Fish Habitat Enhancement

A Manual for Freshwater, Estuarine, and Marine Habitats

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Table of Contents

1 *Ecosytem Functions* *1*
2 *Planning the Project* *21*
3 *Streambank Stabilization* *27*
4 *Riparian Planting* *36*
5 *Streambank Fencing* *50*
6 *Gravel Catchment and Placement* *58*
7 *Gravel Cleaning* *68*
8 *Artificial Spawning Channels* *76*
9 *Artificial Incubators* *81*
10 *Mainstem Rearing Habitat* *91*
11 *Off–channel Development* *107*
12 *Food Production* *115*
13 *Obstruction Removal* *122*
14 *Culverts* *131*
15 *Fishways* *140*
16 *Fish Screens* *148*
17 *Streamflow Control* *157*
18 *Stream Aeration* *164*
19 *Marsh Creation* *170*
20 *Access Improvement* *188*
21 *Woody Debris and Erosion Protection* *196*
22 *Transplanting Eelgrass* *204*
23 *Artificial Reef Creation* *217*

Appendices

Appendix 1 – Wetland Plants *231*
Appendix 2 – Wetland Plants for Marsh Creation *255*
Appendix 3 – Riparian Trees and Shrubs *257*
Appendix 4 – Fish and Crustaceans *286*
Appendix 5 – Fish Production Biostandards *309*

Glossary *320*

1 *Ecosystem Functions*

Introduction

Energy flow and material cycling between the abiotic (non-living) environment and the biotic (living plant and animal) community is the bios of an **ecosystem**. The ecosystem is the basic functional unit in ecology. The biotic component is composed of producers (plants), consumers (herbivores and carnivores) and decomposers. The abiotic components include water, oxygen, and nutrients.

Energy Production and Cycling

Energy, in the form of sunlight, is captured by plants and converted to chemical energy through the process of photosynthesis. This energy is passed from plants to animals, and to other animals along a series of steps known as a **food chain** (Figure 1.1). In most ecosystems, food chains are linked together in complex **food webs** involving many pathways and many different species (Figure 1.2).

During each step in the food chain a portion of the original energy captured by the plant is used for maintenance and is lost as heat. This reduction in energy transfer from one step to the next limits the number of steps in any food chain to four or five. The final consumer in long food chains receives the smallest proportion of the initial energy captured.

A food web is composed of many different feeding levels. These feeding levels, or **trophic levels**, are composed of distinct groups of organisms. These include herbivores, carnivores, omnivores, and decomposers. Herbivores are organisms that feed on plants. They convert the

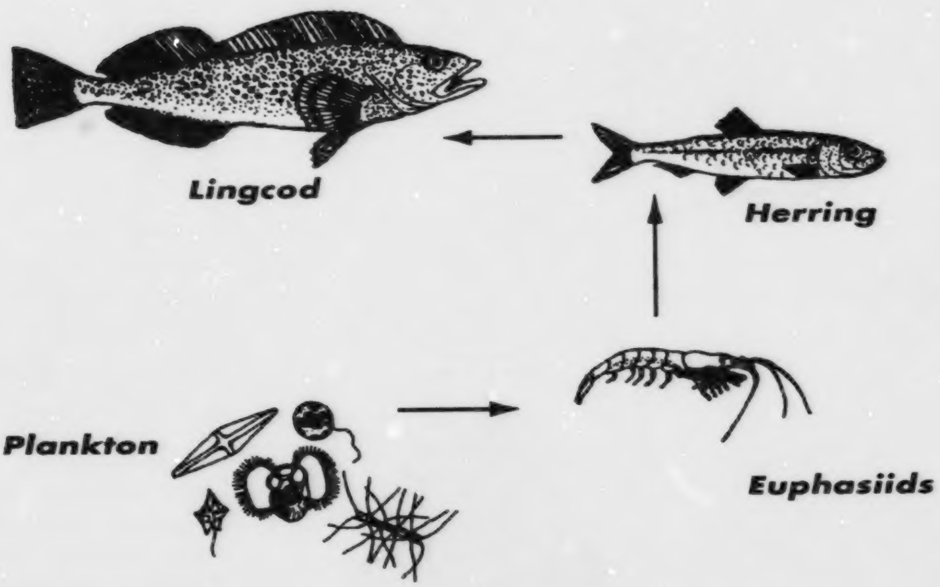

Figure 1.1 A typical coastal marine food chain.

Introduction

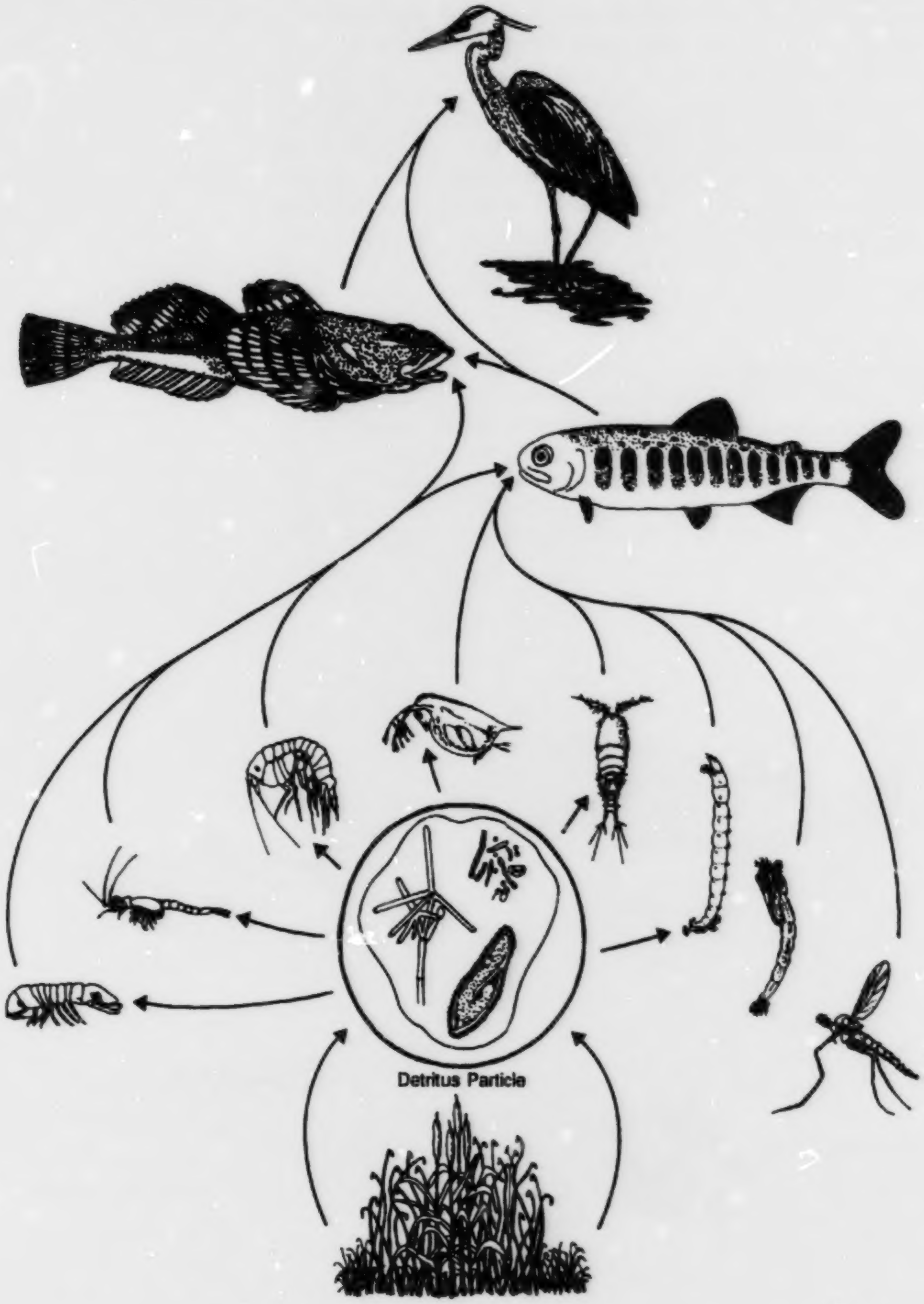
Detritus Particle

***Figure 1.2** A typical estuarine food web.*

Introduction

energy stored in plant tissues into animal tissue. Herbivores in turn are the energy source for carnivores. First level carnivores feed directly on herbivores while second level carnivores feed on first level carnivores. As the feeding level of carnivores increases, their numbers decrease due to the decreasing availability of usable energy. Omnivores are non-specialists that feed both on plants and animals.

Energy stored at the top trophic level is eventually used by a final consumer group of organisms known as **decomposers**. Decomposers subsist on energy provided by dead plant and animal matter. Macro–decomposers (or **detrivores**) in aquatic systems include amphipods, mayfly nymphs, chironomid (midge) larvae, and harpacticoid copepods. These organisms feed on micro-decomposers (bacteria and fungi) as well as organic matter.

Bacteria and fungi are true decomposers which colonize organic matter as they prepare to consume it. The combination of bacteria, fungi, and organic matter is known collectively as **detritus.** Detrivores ingest detritus, metabolize it, and then excrete it. This process reduces the size of the detritus and conditions it for further digestion and final breakdown by fungi and bacteria.

Many essential elements and compounds are cycled between abiotic and biotic systems. These include water, nitrogen, carbon and phosphorous.

The water cycle is the most familiar of all the material cycles (Figure 1.3). It consists of four distinct events: evapotranspiration; condensation and precipitation; storage; and runofff. Water evaporates from the surface of vegetation, wetlands, ponds, lakes, streams, rivers and oceans or is **transpired** by plants to enter the atmosphere. The water vapour in the atmosphere subsequently condenses into clouds and falls to the earth as rain or snow. As the rain or snow reaches the earth, some of it is intercepted by vegetation, organic litter, and man-made structures such as roadways and buildings. The intercepted precipitation or surface water runs off into streams and rivers where it recharges ponds, lakes and/or oceans which serve as resevoirs until the cycle repeats itself.

The carbon cycle is closely tied to energy flow. The source of all fixed carbon is the atmosphere. The cycling of carbon involves its assimilation by plants and its conversion into carbon compounds that compose plant tissue. Herbivores consume plant tissues and synthesize more carbon compounds. Carnivores which feed on herbivores synthesize additional carbon compounds. Some of the carbon is released back into the atmosphere in the form of carbon dioxide, a by-product of respiration. Carbon contained in animal wastes and dead plant and animal tissues is eventually released back into the cycle by decomposer organisms. The rate of release depends upon environmental conditions such as soil moisture, temperature, and precipitation.

Other important nutrients, such as phosphorous and nitrogen, undergo similar cycles, differing only in specific details.

The Freshwater Environment

The Stream Ecosystem

The streams and rivers of British Columbia and the Yukon provide spawning and rearing habitat for nine species of **anadromous** salmon, trout, and char.

Varying flow velocities within the course of a stream create both erosion and deposition zones. The erosion zone of a stream occurs where the water velocity is fast enough to carry small particles in suspension. Riffles characterize this zone. Depending on the current velocity, the riffle will consist of either sand, gravel, and/or cobble. The deposition zone is characterized by slow current velocities where small sediment particles fall out of suspension. Large streams and rivers possess deposition zones. Pools, slow backwaters, and slow reaches and edgewaters are typical depositional habitats.

Streams commonly exhibit a gradual transition from higher gradients in headwaters to lower gradients at their mouth. Accompanying this transition is a decrease in the size of stream bottom sediments, widening of the channel and an increase in the incidence of side channels and pools. Salmonids most often exploit stream habitats that exhibit a high to medium gradient with an abundance of boulders, rocks and gravel.

Riffles and pools are the dominant habitat types in streams. Riffles are the primary food producing areas. They usually exhibit a relatively diverse array of insect fauna. Pools and slow water habitats have fewer bottom dwelling insect species than riffle habitats. However, these slow water habitats, even though characterized by few species, often support large numbers of individuals.

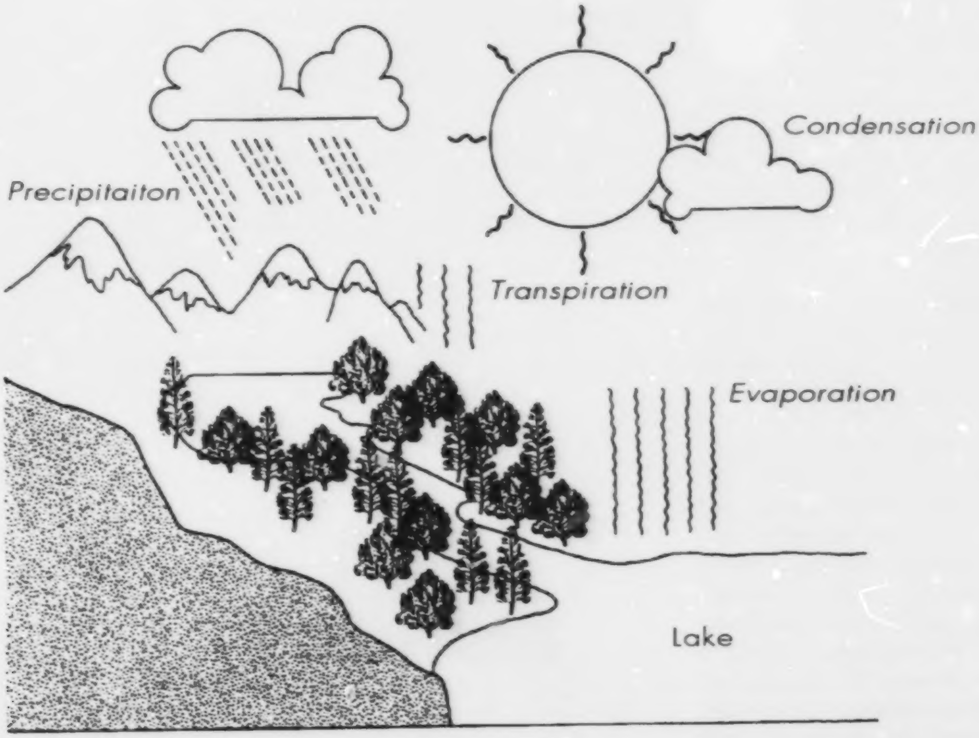

Figure 1.3 The water cycle.

The Freshwater Environment

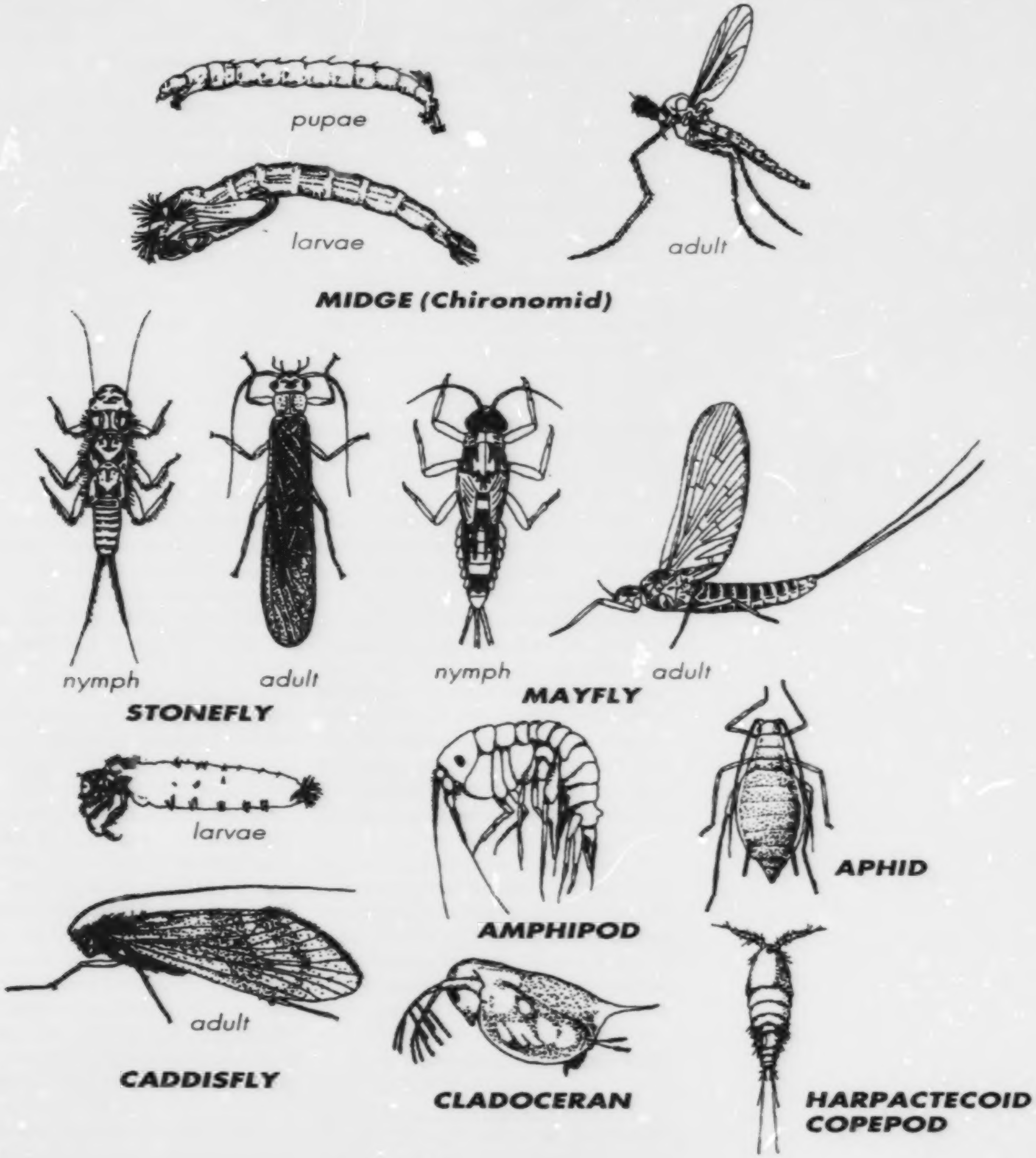
pupae
larvae
adult
MIDGE (Chironomid)
nymph
adult
STONEFLY
nymph
adult
MAYFLY
larvae
adult
CADDISFLY
AMPHIPOD
APHID
CLADOCERAN
HARPACTECOID
COPEPOD

Figure 1.4 Examples of insect groups commonly taken as food by juvenile salmonids.

The Freshwater Environment

The major food item of stream rearing **salmonids** are aquatic insects. The majority of these insects reside in the stream during the larval or nymph stages of their life histories. These immature insects emerge at the water surface as adult flying or crawling insects. Some of these insects are carnivorous, such as the stonefly, which feeds mainly on other insects. Others such as true flies and mayflies are generally herbivorous. They feed on decaying grasses, leaves from deciduous shrubs and trees, and needles from coniferous trees, (as well as colonies of bacteria and fungi which colonize the organic matter). Some insects also graze on algae found on the rocks and boulders of the stream bed. Examples of insect groups commonly eaten by juvenile salmonids are shown in Figure 1.4

The majority of insects eaten by juvenile salmonids are taken as drift. Aquatic insects exhibit a tendency to leave their positions among the rocks and gravel of riffles and drift downstream for a short distance before they re-attach. These drift insects are supplemented in the diet of juvenile salmonids by terrestrial insects that fall on to the water surface from streamside vegetation.

The Estuarine Environment

An estuary occurs where freshwater originating from land drainage mixes with seawater. Highly visible estuaries are located where major rivers discharge into coastal marine habitats. Estuaries function as nurseries for the juvenile stages of many fish species some of which have substantial commercial and recreational value. For anadromous species, estuaries act as a transition or buffer zone where migrating juveniles and adults gradually adapt to environmental differences between freshwater and saltwater habitats.

Chum and chinook salmon, and to a lesser extent coho salmon, temporarily reside in estuaries prior to moving into the marine environment. Tidal creek, drainage channels and eelgrass meadows are preferred habitats. Major prey items tend to be invertebrate detritus feeders.

The Eelgrass Ecosystem

Eelgrass (Zostera marina) occurs in many estuarine habitats along the Pacific coast of Canada. This rooted seed plant inhabits aquatic environments with salinities of 10 to 30 parts per thousand and temperatures of 10 to 20 degrees Celsius. It may be found on firm sand, firm mud, or mixed sand/mud substrate. It is found in low energy regimes at a depth of +1.8 m to -6.6 m (**chart datum**). The upper intertidal distribution of eelgrass is limited by **desiccation**. The lower limit of distribution is determined by a number of interrelated factors that include substrate type, energy regime, and light availability.

Eelgrass forms extensive meadows that function to stabilize sediments and provide refuge and feeding habitat for a vast array of organisms. In summer months, eelgrass leaves are colonized by large numbers of **diatoms**, small single-celled algae, that form a fuzzy brown film. Detritus and unassociated bacteria soon become incorporated into this film. This diatom-bacteria-detritus film, together with decaying eelgrass leaves, is an important food source for many protozoans, microscopic worms, and small crustaceans.

The eelgrass **faunal community** includes several species of sea stars, snails, clams, isopods, amphipods, copepods and crabs. The dominant herbivores in eel-

The Estuarine Environment

grass systems are waterfowl. Black brant, Canada geese, wigeons, scoters, canvasback ducks, and coots feed on eelgrass leaves, while pintails, mallards, and green-winged teals feed on eelgrass seeds. Many shorebirds feed on fauna associated with eelgrass during low tide. Several species of fish use eelgrass meadows for shelter and food either as juveniles or adults. These include juvenile salmon, herring, gunnels, various sculpins, rockfish, greenlings, sole, cabezon, tubesnouts, pipefish, and surfperch.

Pacific herring and chum salmon are commercially important species that are dependent on eelgrass for part of their life cycle. Eelgrass is one of the most important substrates for the attachment of herring eggs. Eelgrass also provides important rearing habitat for chum salmon. Small crustaceans known as harpacticoid copepods constitute the most important prey item for chum salmon while they rear in the estuary. These small crustaceans and other sediment dwelling invertebrates occur in eelgrass at far greater densities than in adjacent non-vegetated mudflats and sandflats.

The refuge role of eelgrass is related to its food production. Animals using the cover afforded by eelgrass can allocate more effort and energy to feeding and growth and less energy to avoid predation. Juvenile Dungeness crabs can be found in large numbers in eelgrass meadows. This is due to the relatively high number of hiding places from predators afforded by meadows as compared to adjacent mudflats and sandflats. Food items such as small crustaceans and molluscs are also very abundant in eelgrass. The eelgrass meadow, therefore, provides juvenile Dungeness crab both protection from predators and a readily available food supply.

The Tidal Marsh Ecosystem

The estuarine tidal marsh community is composed of many different plant species. Distinctive vegetation zones exist along a vertical gradient (Figure 1.5). Distinct vegetative zones occur in tidal marshes as a result of several physical parameters, the most important being substrate elevation. The duration of tidal inundation is determined by substrate elevation which in turn determines the plant species present in each marsh type. **Salt marsh** can be identified by such dominant plant species such fleshy jaumea, pickleweed, saltmarsh bulrush, and tufted hairgrass. **Brackish marsh** is dominated by Lyngby's sedge, American threesquare, soft-stem and hard-stem bulrush, assorted rushes and cattail. Dominant plant species in **fresh marshes** include slough sedge, beaked sedge, soft-stem and hard-stem bulrush, small fruited bulrush, assorted rushes, horsetail, cattail and reed canary grass.

Estuarine tidal marshes are important in sustaining fish species that reside in estuaries all or part of their lives. In addition to providing refuge, they also play a vital role in the food web dynamics of many fish species. Most of the net **primary production** from tidal marshes is channelled through the detritus food chain. Invertebrates serve as the trophic connection between detritus and fish.

The most common species of fish found in tidal marshes are peamouth chub, prickly sculpin, chum salmon, chinook salmon, starry flounder, threespine stickleback, and largescale sucker. Other species found on occasion include sockeye salmon, coho salmon, redside shiner, brassy minnow, longfin smelt, squawfish, and Pacific staghorn sculpin.

Juvenile fishes feed on an abundant array of invertebrates that reside in brackish and salt marshes. These include benthic dwelling crustaceans such as the free

The Estuarine Environment

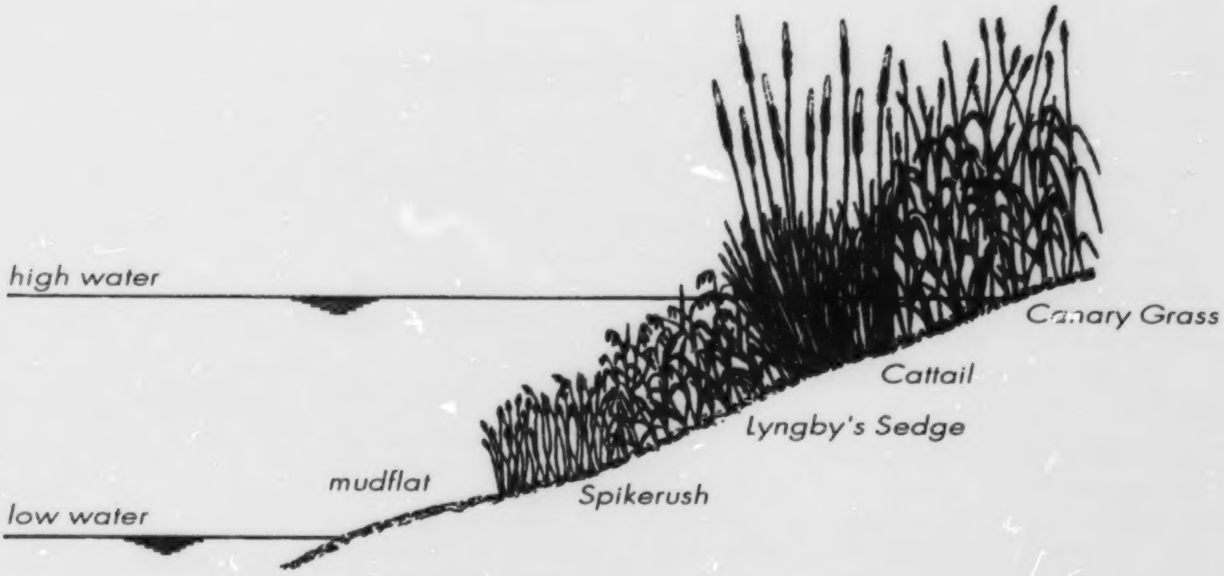

Figure 1.5 Vegetation zones associated with a typical tidal marsh.

swimming amphipod Eogammarus confervicolus, the tube dwelling amphipod Corophium spinicorne, and harpacticoid copepod species that inhabit bottom sediments and the root masses of marsh plants. Other invertebrate food species include mysids, calanoid and cyclopoid copepods, midge (chironomid) larvae and pupae, and tubificid worms.

In fresh tidal marshes mayflies, dragonflies, damselflies as well as midges are taken during their larval, pupal, and adult stages. Cladocerans (daphnia) are also consumed by juvenile fish species.

The Marine Environment

The Reef Ecosytem

A reef is a coastal marine feature characterized by hard substrates that provide a diversity of microhabitats to a large assemblage of aquatic plants and animals. A reef may be a rocky outcrop, a rock wall or shelf, or a man-made structure such as a **groin**, **jetty** or **piling**.

Hard substrate is required for the successful colonization of encrusting animals and the attachment of kelp and other marine algae. These organisms, once established, function to increase the habitat complexity of the reef system. They also provide a multitude of microhabitats for small invertebrates that comprise the lower trophic levels of the reef food web. In addition to food, the reef complex provides shelter and refuge for many fish species and a variety of **motile invertebrates**.

The Marine Environment

Several green, red, and brown algae may be found attached to the hard substrates of reefs. Within the intertidal and subtidal regimes of sheltered bays and inlets, specific algal species are found within specific tidal zones. The lower intertidal zone is dominated by the brown algae Fucus distichis and red algae Petrocelis middendorffii. The lower intertidal to subtidal fringe supports the red algal species Iridaea cordata, Porphyra perforata, Gigartina exasperata, the green algae Ulva lactuca, and the brown algae Laminaria spp., Sargassum muticum and Nereocystis luetkeana.

Encrusting organisms that colonize and inhabit the hard substrates of reefs include plumose anemones, barnacles, mussels, hydroids, sponges and corals. Motile microinvertebrates that feed on algal and detrital matter, and constitute an important component in fish and larger invertebrate diets, include mysids, amphipods, copepods, isopods, nereid worms and the larval forms of macroinvertebrates such as shrimps and crabs. Motile macroinvertebrates inhabiting reef systems include crabs, shrimp, sea stars, and abalone.

Common fish inhabitants of reefs include kelp greenling, lingcod, rockfish, blackeye goby, striped surfperch, and several sculpin species. Blackeye gobies are one of the smaller fish inhabitants of the reef. They feed on copepods, barnacle larvae, and bivalve larvae. The somewhat larger striped seaperch consumes small crustaceans, a variety of worms, and mussels. Rockfish and kelp greenlings consume worms, crustaceans, and small fish. Sculpins, such as cabezon and Red Irish Lord, will eat fish, crabs, shrimp, barnacles and mussels. Lingcod is the most voracious common reef inhabitant and will consume a variety of fish species including rockfish and large invertebrates such as crabs, shrimp and octopus.

Life Histories

Salmonid Fishes

The streams of British Columbia and the Yukon support nine anadromous fish species of the Family Salmonidae. These include five species of Pacific salmon (coho, chinook, chum, sockeye, and pink), two species of trout (steelhead and cutthroat), and two species of char (Dolly Varden and Arctic char). Each of these species has a unique life cycle and freshwater habitat requirements. Understanding the requirements of each species and the factors that limit their production is essential to developing and implementing effective enhancement programs.

The most striking characteristic of anadromous salmonids is their tendency to return from the ocean to their **natal stream**. All species require a freshwater environment for spawning and embryonic development; however, each species differs in the extent to which they rear in freshwater.

All species use the gravel bottom of streams or upwelling groundwater sources for spawning. The spawning nest, or **redd,** is constructed by the female. It consists of a series of pockets dug in the gravel to a depth of 20 to 50 cm. The eggs are deposited into the redd. An **alevin**, a small fry with an attached yolk sac, emerges from the egg into the gravel. Once the yolk sac has been completely absorbed, the alevins emerge as fully developed fry from the gravel. The length of incubation and the timing of fry emergence varies among species and is temperature dependent.

Life Histories

There are significant differences in the life histories of Pacific salmon, trout and char. Pacific salmon die after spawning while trout and char may survive to spawn more than once. Salmon and char tend to spawn in the fall as temperatures decrease. Trout spawn in late winter or spring as temperatures begin to increase.

Freshwater rearing requirements vary among species. Pink and chum salmon migrate to the sea immediately after emerging from the gravel as fry. The remaining salmonids may rear in streams, lakes or estuaries for periods of months or several years before entering saltwater.

Pacific salmon and steelhead undertake extensive feeding migrations in the Pacific Ocean between northern California and the Gulf of Alaska while Dolly Varden, Arctic char and coastal cutthroat trout generally remain in coastal waters.

Typical salmonid life cycles are shown in Figure 1.6 and a guide to the identification of adults and juveniles is presented in Appendix 4.

Coho Salmon

Coho (Oncorhynchus kisutch) spawn in almost all coastal rivers and streams accessible to them. They inhabit 970 recorded small streams and rivers as well as many unrecorded watercourses. Coho are known to migrate and spawn 500 km up the Fraser and Skeena river systems.

Mature coho migrate into streams during September to November and generally spawn from mid-October to mid-December. Spawning may take place as late as February. Mature adults commonly weigh between 2.5 and 5.5 kg. The number of eggs carried per female, otherwise known as **fecundity**, ranges from 2500 to 5000. Coho fry emerge during April and May and feed primarily on aquatic and terrestrial insects during their freshwater rearing phase. This lasts 1 year in southern British Columbia and may last up to 2 years in northern areas of the province. Seaward migration takes place during May and June. The seaward migrants or **smolts** generally measure 8 to 12 cm long at time of migration.

Coho mature after 2 years in the ocean. In their early stages of ocean residence they remain near the surface feeding on larval fishes, insects, and crustaceans. As they migrate offshore their diet changes to include squid, euphausiids, and fish. Some coho mature after only 1 summer of ocean life. These precocious males known as "jacks" weigh an average of 0.5 kg and are much smaller than normal mature coho.

Chinook Salmon

Chinook salmon (Oncorhynchus tshawytscha) are the largest of the Pacific salmon. They are generally associated with larger rivers. Certain races of chinook salmon migrate farther than any other anadromous species. They spawn above Prince George in the Fraser system and in the upper Yukon River, as far as 2900 km from the sea.

The extent to which chinook salmon rear in freshwater and reside in the ocean varies from one population to another. In southern coastal populations chinook juveniles tend to rear only 2 to 3 months in the natal stream or estuary. In northern and interior regions juvenile chinook may rear in freshwater for one (1) full year. The majority of chinook salmon mature after 3 to 5 years of ocean residence.

The timing of spawning also varies from one population to another. Populations that spawn in streams far from the sea, such as those in the upper Fraser River, commence their migration as early as May or June before spawning in September. Coastal populations enter their spawning stream in September or October. Spawning occurs approximately one month later.

Life Histories

Most mature chinook weigh between 7.0 and 12.0 kg, however, some may reach 40 kg. Fecundity is in the range of 4,000-6,000 eggs. Chinook eggs are the largest of the salmon.

Chinook fry emerge during March and April. Individuals of populations that reside in the stream for only 2 to 3 months migrate to the sea in July at a length of 6 to 9 cm. Those individuals of populations residing in streams for one year tend to migrate to the sea in April to May at a length of 8 to 10 cm.

Juveniles rearing in streams feed primarily on aquatic insects. Juveniles rearing in the estuaries of large rivers feed on small fishes and crustaceans. Fish such as sand lance, pilchard, herring and rockfish as well as euphausiids are the primary prey of chinook during feeding migrations off the British Columbia coast.

Pink Salmon

Pink salmon (Oncorhynchus gorbuscha) are the most abundant salmon species in British Columbia. A few major river systems account for most of the fish's production. Pink salmon enter coastal rivers and streams during September and October. The invariable two-year life cycle of the fish effectively isolates fish running in odd-numbered calendar years from fish running in even-numbered years. There is no interbreeding between the two cycles. Within a given geographic region either the odd-year or even-year population dominate, and in some instances one cycle is completely absent.

The average weight of mature pink salmon is between 1.5 kg to 2.5 kg. Females usually carry between 1500 and 1900 eggs. The eggs hatch in late February and the young emerge from the gravel in April or May depending on water temperature. The young actively migrate downstream upon emergence. During their first summer the fish rear in marine coastal waters. At the end of summer young pinks move offshore into deeper water.

Juvenile pink salmon feed mainly on copepods. This small crustacean is supplemented by other organisms such as insects, Oikopleura, chaetognaths, amphipods, euphausiids, and an assortment of small fishes. During their offshore migrations pink salmon feed mainly on euphausiids, copepods, amphipods, fish, and squid.

Sockeye Salmon

Sockeye salmon (Oncorhynchus nerka) spawn in rivers with lakes in their systems. Major spawning habitats for sockeye occur in the Fraser, Skeena, and Nass rivers, and the Rivers and Smith inlet systems.

Mature fish weight and fecundity varies between the populations of different river systems. Mature sockeye weigh between 2.0 and 5.0 kg. Fecundity ranges between 2500 and 4500 eggs.

Adult sockeye enter spawning rivers between June and September. Spawning takes place in September or October in either lake inlet streams or lake outlets. Some populations spawn in groundwater fed gravels along the shorelines of lakes. Sockeye fry emerge from the gravel in April or May and migrate directly to a lake. Most British Columbia sockeye spend 1 year in freshwater before migrating to the sea. During this year of lake residence sockeye juveniles feed mainly on zooplankton dominated by cladocerans, copepods, and amphipods. On reaching saltwater juvenile sockeye appear to remain inshore early in their first summer. Some individuals temporarily reside within the freshwater influence (i.e. estuary) of their home river. Juvenile sockeye feed on a variety of crustaceans and larval/young fish during this period of their life history.

Life Histories

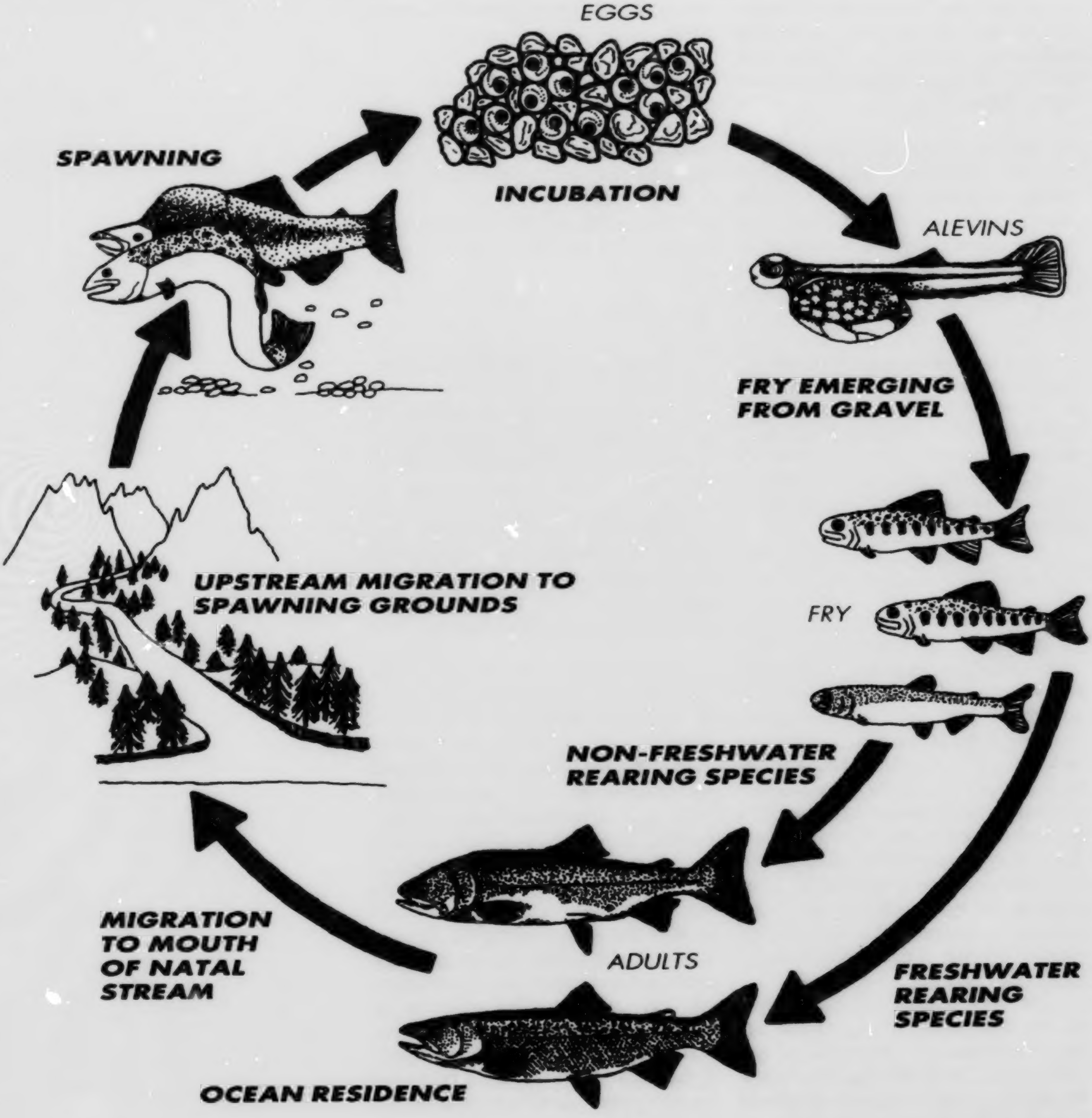
EGGS
SPAWNING
INCUBATION
ALEVINS
FRY EMERGING FROM GRAVEL
UPSTREAM MIGRATION TO SPAWNING GROUNDS
FRY
NON-FRESHWATER REARING SPECIES
MIGRATION TO MOUTH OF NATAL STREAM
ADULTS
FRESHWATER REARING SPECIES
OCEAN RESIDENCE

***Figure 1.6** The anadromous salmonid life cycle.*

Life Histories

Most sockeye spend 3 to 4 years in the ocean before reaching maturity at an age of 4 to 5 years.

Chum Salmon

Chum salmon (Oncorhynchus keta) spawn only in coastal streams, generally within a few kilometres of saltwater. Chum salmon are second only to coho in terms of geographic distribution and are present in most coastal streams.

Chums usually mature at 3 to 5 years, and weigh an average of 3.5 to 5.5 kg. The adults enter streams just prior to spawning. Spawning may be as early as August in northern regions. Depending on the population, spawning in southern systems occurs between October and January. Fecundity ranges between 3,000 to 3,500 eggs.

Fry emerge from the gravel in April and May and migrate directly to the sea. Chum are similar to pink salmon as both lack a freshwater rearing phase. However, in large rivers such as the Fraser, where downstream migration distances are relatively long, fry may feed during the migration, displaying modest growth before reaching saltwater. During this downstream migration the primary food is insect larvae. Upon reaching saltwater, they remain inshore until the end of summer, moving offshore in September. During this inshore phase their diet consists mainly of copepods, insects, and Oikopleura. The main food items during their offshore phase are euphausiids, squids, amphipods, and crab larvae.

Steelhead Trout

Steelhead trout (Oncorhynchus mykiss) populations occur in most coastal streams. They can migrate as far as 500 km up the Fraser and Skeena river systems to spawn. The freshwater races of this salmonid are commonly called rainbow trout.

Mature fish weigh between 3.0 and 8.0 kg. Average steelhead fecundity ranges between 3,000 and 4,000 eggs.

Steelhead enter spawning streams during every month of the year. Populations are accordingly categorized as winter-run (November to May) or summer-run (June to October). The time of spawning also varies from one population to another. In southern coastal systems spawning may take place as early as January. In northern and interior systems regions it may take place as late as June. Steelhead fry generally emerge in June or July. They rear for either 2 or 3 years in the natal stream or in a lake before migrating to sea as smolts from April through June.

Steelhead usually return to spawn after 2 to 3 years in the ocean. The common age of spawning adults is 4 to 6 years. Only a small proportion of adults, usually females, return to spawn a second or third time. The proportion of repeat spawners averages about 10 percent.

Cutthroat Trout

Coastal cutthroat trout (Oncorhynchus clarki clarki) are widely distributed in coastal streams and lakes of British Columbia. There are both anadromous and freshwater races of cutthroat trout. Cutthroat streams tend to be of smaller size than those that support steelhead. Cutthroat trout often occupy streams that also support coho salmon.

Anadromous cutthroat spend 1 or 2 summers in the ocean before returning to spawn for the first time. They generally enter spawning streams from October to December. Spawning occurs from January to March. Average fecundity varies between 800 and 1500 eggs, depending on the population.

Life Histories

Cutthroat fry emerge in June and July. In southern British Columbia, the majority of juveniles rear in the natal stream for 2 or 3 years before migrating to saltwater. Upon reaching the ocean, cutthroat generally remain in coastal habitats within 10 km of their natal stream. Coastal cutthroats usually mature at 3 to 4 years of age, at which time they weigh an average of 0.8 kg.

Juveniles feed primarily on aquatic and terrestrial insects in their natal stream. Fry may migrate to estuaries and take up residence for 1 or more years. During their estuarine residence they consume primarily crustaceans, insects, and small fishes.

Dolly Varden

Dolly Varden char (Salvelinus malma) occur throughout British Columbia. Interior populations are freshwater resident, while coastal populations are typically anadromous except where populations are landlocked by impassible barriers. The life history of anadromous populations of Dolly Varden has not received much study, and is therefore not very well understood.

Sexual maturity is believed to be at 3 to 6 years. Males often mature a year earlier than females. Dolly Varden spend 2 to 4 years in freshwater in their natal stream. Anadromous stocks migrate seaward from late May to early June. They spend anywhere from 60 to 160 days in the sea, moving only short distances from the river mouth. They migrate into spawning rivers in late summer or fall. Spawning occurs during October and November.

The food of stream resident young include aquatic and terrestrial insects, snails, leaches, and salmon eggs. Adults follow salmon upstream during the fall and feed on eggs that drift down from spawning areas. Juvenile salmon, (both fry and smolts), are also a common food source for Dolly Varden in the spring.

Arctic char

Arctic char (Salvelinus alpinus) are indigenous to the northern Yukon. Arctic char are similar to Dolly Varden in that they may be freshwater resident or anadromous.

Arctic char migrate to spawning habitats in early autumn and usually spawn soon afterward in September or October. They spawn in the quiet pools of rivers at depths of 1.0-4.5 meters, or in the gravel or rocky shoals of lakes. Fecundity ranges between 3000 and 5000 eggs. Fry emerge about mid-July. Juveniles move downstream to the sea the following spring once they reach lengths of 15 to 20 cm. Arctic char tend to remain in the vicinity of the mouth of their natal stream or river.

The average weight of mature anadromous Arctic char ranges between 0.9 and 4.5 kg.

An identification key outlining the major distinguishing features of fish and invertebrates discussed below is presented in Appendix 4.

Non-salmonid Coastal Marine Fish and Invertebrates

Rockfish

In British Columbia there are 36 known species of rockfish, 34 of which belong to the genus Sebastes, and 2 to the genus Sebastolobus. The majority of species inhabit coastal marine waters. Each species inhabits a specific depth range, from kelp beds in the low intertidal zone to 900 m. Rockfish are primarily bottom species. Sebastolobus spp. are essentially deep water fish, occurring at depths greater than 90 m. Sebastes spp. are found near the surface as well as in deep waters. Common shallow reef inhabitants include copper rockfish, quillback rockfish, china

Life Histories

rockfish, brown rockfish, and black rockfish. Sebastes spp. give birth to live young (larvae). The reproductive cycle consists of insemination (transfer of sperm to the female), followed by fertilization and parturition (release of larvae). Females are usually inseminated in the autumn. Actual fertilization of the eggs takes place in the winter or early spring. Developed larvae are released between January and May. An adult female may release 200,000 to 800,000 larvae, depending on the species and size of the female.

During the first stage of development the larvae are pelagic and live near the surface for some time before settling to the sea bottom. Species are difficult to differentiate during this early planktonic stage. It is not until the larvae develop into juveniles that species can be readily identified.

As adults some species of Sebastes form large schools while others inhabit rocky areas. Rockfish consume a variety of organisms that include herring, sand lance, crabs, shrimp, and euphausiids. They are considered opportunistic feeders.

Males reach sexual maturity at an earlier age than females of the same species. Adult females are usually larger than males of the same age. Sexual maturity for both sexes ranges from 2 to 18 years depending on the species concerned.

Lingcod

Contrary to its common name, lingcod (Ophiodon elongatus) is not a true cod. Lingcod are found throughout coastal British Columbia. They are found in very shallow waters to depths greater than 200 m. Preferred habitat includes rocky areas and the edges of underwater reefs.

Lingcod spawn from December to March. Females deposit their eggs in shallow water in crevices or under rocks. These areas are usually exposed to relatively strong currents. This ensures an adequate oxygen supply for developing eggs. The eggs, pinkish and 3.5 mm in diameter, are deposited in large sticky masses, some of which weigh as much as 14 kg. The eggs harden and develop a tough membranous shell when exposed to water.

The male guards the eggs against predators. The eggs hatch 7 weeks after being spawned. Hatching is progressive , with the eggs on the outside of the mass hatching first. The larvae, about 7 mm in length, swim immediately to surface waters where they feed exclusively on zooplankton (copepods and other small crustaceans). In late May, when the fish reach approximately 8 cm in length, they migrate to the sea bottom, where their diet changes to small fish. The juvenile fish remain in groups for about one year, at which time they disperse into reef habitats.

Lingcod mature at 4 to 5 years. At this age, mature females are 65 to 75 cm in length and weigh from 2.7 to 4.5 kg. At 10 to 14 years adult females may attain lengths of 100 cm or more. Comparatively, males are smaller, ranging from 46 to 51 cm at maturity to only 90 cm at 10 to 14 years. The adult lingcod is a voracious predator, feeding on herring, sandlance, cod, rockfishes, flounders, hake, pollock, and octopus as well as members of its own species.

Surfperches

Three common surfperches in British Columbia are the shiner perch (Cymatogaster aggregata), striped seaperch (Embiotoca lateralis) and pile perch (Rhacochilus vacca). All 3 species give birth to live young.

The pile perch grows to 44 cm. and bears young in August. The pile perch

Life Histories

eats mussels, crabs, and barnacles. It inhabits rocky shores, around pilings, wharfs, and other underwater structures. Its preferred depth range is from surface water to 46 m.

The shiner perch is smaller than the pile perch, growing to approximately 15 cm. The breeding season for shiner perch lasts from April to July. The sperm is stored by the female in a compartment of the ovary for 5 to 6 months until November or December, at which time the sperm penetrate the eggs and gestation begins. An average of 10 young are born in summer (May through August). The males are mature at birth. The early food of shiner perch is primarily copepods. Adults feed on mussels, barnacles, and algae. The shiner perch is found in shallow water in and about eelgrass beds, pilings, and wharfs, however it can also be found to depths of 146 m. The shiner perch may enter brackish and even fresh water habitats.

The striped seaperch grows to 38 cm. Young are born in June and July. As many as 44 individuals may be born at one time. The striped seaperch eats small crustaceans, worms, mussels and herring eggs. It generally inhabits rocky environments and kelp beds, but may be found occasionally over sandy regions near rocky outcrops to depths of 21 m.

Herring

Pacific herring (Clupea harengus pallasi) grow to 20-25 cm. The average life span of herring is 9 to 10 years. Herring rarely weigh more than 500 grams.

Herring spawn from February to April. The heaviest spawning occurs during March. Egg deposition is usually on marine vegetation such as eelgrass, rockweed (Fucus distichus), and assorted red and brown algae distributed throughout the intertidal and high subtidal zones.

The eggs hatch simultaneously, 10 to 21 days after they are spawned. The larval herring are about 9 mm in length and feed mainly upon invertebrate eggs, copepods, and diatoms. Approximately 10 weeks after hatching herring larvae undergo a three week metamorphosis into immature herring, known as juveniles. Juvenile herring form large schools that number in the millions. In September, these schools gradually move seaward to deep offshore feeding grounds (150-200 m). Here the herring feed on zooplankton dominated by amphipods, euphausiids, and copepods.

Depending on the population, herring mature in their second, third, or fourth year. Adult herring feed on larger forms of crustaceans and small fishes.

Dungeness Crab

Dungeness crab inhabit bays, inlets, and the saltier environments of estuaries from low water to depths of 180 m. It is most abundant in habitats that possess both bare sandy substrates and eelgrass beds.

Breeding occurs during summer, however the eggs are not fertilized and spawned until autumn. An estimated half-million to 1 million fertilized eggs are brooded in the abdomen of the female until spring.

During the first four months, the young crabs are free swimming. The shrimp-like larval crab passes through five developmental stages termed **zoea.** It is during the last developmental stage that the young crab, known as a **megalops,** first appears to look like a juvenile crab.

As a crab grows, it sheds its outer **exoskeleton** in a process called **moulting**. After shedding its old shell, the crab swallows water and swells to a larger size. Shell hardening and an accompanying gain in weight occurs in the next 3 months.

Life Histories

The male Dungeness crab grow to a maximum width of 23 cm and weight of approximately 2 kg. Females are substantially smaller. A crab matures at 10 to 11 moults, 2 or 3 years after bottom settlement. The male reaches the legal harvestable size (165 mm) at approximately 4 years. Females rarely reach legal size.

The Dungeness crab prefers live prey such as clams, other crustaceans and small fish. Cannibalism occurs among young crabs shortly after they settle out on the bottom. The crab feeds mainly on animals living partly or completely buried in sandy substrates, and obtains its prey with its claws.

Shrimp

Six species of small shrimp belonging to the family Pandalidae occur off the Pacific coast of British Columbia in sufficient numbers to support several small commercial and recreational fisheries. They are similar in size and appearance and share similar life histories.

Mature shrimp breed in late autumn or early winter. The developing eggs are carried on the swimming appendages of the female's abdomen, where they remain until they hatch in the spring. After hatching, the shrimp larvae swim freely for about three months whereupon they settle to the bottom and develop into mature individuals.

Shrimp initially mature as males in the first or second year, approximately 6 or 18 months respectively after hatching. They spend 1 or 2 seasons as sexually active males until physiological changes occur that transform them into viable females. All six species undergo this transformation, known as protandic hermaphrodism, however, some species do have large proportions of individuals that bypass the male stage entirely.

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2 *Planning the Project*

Introduction

Habitat enhancement projects must be carefully selected and planned. The limitations regarding the ability of each habitat type to produce fish must be identified. Once identified, an enhancement strategy can be selected that will offset and/or correct those factors limiting production.

The need for habitat enhancement must be based on a competent diagnosis of habitat quality by a fisheries biologist or technician trained in the habitat type of concern. Each site must also be examined for its potential contribution to existing stocks within the system.

Seasonal restrictions usually apply to enhancement work. These will depend on the habitat type and whether the work is in-water or based on dry land. It is essential that existing fisheries resources not be compromised by the enhancement project. Consideration must be given to the effects of the enhancement activities on all species within the system, not just the target species. The assistance of a habitat and/or stock biologist should be sought when developing plans and proposals for habitat enhancement projects. Professional input should come early in the planning stage before any intensive effort is expended.

Salmonid Stocks and Habitat Inventory

The present status and historical abundance of salmonid populations and habitat types should be determined. This information will be different for each habitat type (e.g. interior stream vs. estuarine marsh). Historical, existing, and potential rearing and spawning habitats should be identified during the pre-development stages of any enhancement plan. Information regarding existing fisheries resources can be obtained from local and district offices of the Department of Fisheries and Oceans or from the regional offices of the B.C. Fish and Wildlife Branch. Project files and technical reports will contain most of the information. Interviews of local fishery agency personnel may reveal important information that would not be available from technical reports or publications.

Water and Land Use

Historical, existing and potential land and water use activities that may have an affect on enhanced habitat should be taken into account when planning a project. Historical information may help to explain the present status of fish stocks and/or habitat. Proposed land or water uses that may adversely affect the project must be investigated when determining project feasibility.

The Department of Fisheries and Oceans and the B.C. Fish and Wildlife Branch may be able to provide information on the various water and land use activities that may affect the project. Other direct sources are:

Water Management Branch, B.C. Ministry of Environment

This agency issues licenses and approvals for activities in and about a stream, such as: modifications to the channel, construction of flood channels and flood

Water and Land Use

and flood control structures, construction and operation of dams for water storage and diversion, and withdrawal of water from streams. Information concerning water licenses and their conditions may be obtained from the office of the Regional Engineer.

Waste Management Branch, B.C. Ministry of Environment

Information concerning permits to discharge effluent into a stream, and the conditions of those permits, may be obtained from the regional offices of this agency.

Land Title Office

Any questions of land ownership and the status of land in the watershed should be directed to the local land title office.

B.C. Ministry of Forests

Information on forest harvesting activities, development plans and access to forested areas may be obtained from the district office of the Ministry of Forests.

Regional Harbour Commissions

Information on existing foreshore leases within jurisdictional port boundaries can be obtained from regional harbour commissions. The location and configuration of estuarine and marine enhancement projects will be determined by existing foreshore leases.

B.C. Ministry of Crown Lands

Information on existing foreshore leases outside port boundaries can be obtained from the Ministry of Crown Lands. The location and configuration of estuarine and marine enhancement projects will be determined by existing foreshore leases.

Canadian Wildlife Service, Environment Canada

Information on important waterfowl nesting areas and overwintering sites can be obtained from the Canadian Wildlife Service regional office. Other wildlife information may be obtained from the Canadian Wildlife Service or the B.C. Fish and Wildlife Branch.

Municipal and Regional Governments

Municipal or regional government offices can provide information concerning land use plans and developments proposed for areas surrounding the proposed enhancement project.

Legal Considerations

There are several pieces of legislation that may apply directly or indirectly to a habitat enhancement project. The principal statutes are:

Fisheries Act of Canada

The Fisheries Act contains provisions that prevent the harmful alteration of fish habitat, obstruction of fish, and the depositing of substances deleterious to fish. It also regulates activities involving the capture, holding, retention, transfer and breeding of fish. This Act is administered by both the federal Department of Fisheries and Oceans and the B.C. Fish and Wildlife Branch. In British Columbia, the federal agency is responsible for the man-

Legal Considerations

agement and protection of marine fishes and Pacific salmon. Responsibility for management and protection of all freshwater fish, and anadromous species other than salmon (i.e. steelhead and cutthroat trout and Dolly Varden char) has been delegated to the provincial agency. In the Yukon, the federal agency is responsible for all anadromous fish. All fish habitat enhancement projects in British Columbia require the approval of both the B.C. Fish and Wildlife Branch and the Department of Fisheries and Oceans. Fish habitat enhancement projects in the Yukon require approval of Department of Fisheries and Oceans.

Water Act of British Columbia

The Water Act pertains to any activities that could affect either the volume of water flowing in a stream of the shape/configuration of the stream channel. An approval or license must be obtained from the Comptroller of Water Rights before any work is carried out in a stream or river.

Northern Inland Water Act

Under the Northern Inland Water Act, the Yukon Territory Water Board issues licenses and permits to use water and to discharge waste into water in the Yukon.

Harbour Commissions Act of Canada

The Harbour Commissions Act pertains to any activities within port boundaries. These activities must not compromise the integrity and efficiency of the port system and the optimum deployment of resources. Approval must be obtained from the local Harbour Commission before any work is carried out within port boundaries. All ports in British Columbia are in estuarine or marine waters.

Navigable Waters Protection Act of Canada

The Navigable Waters Protection Act regulates any activity within navigable waters. Navigable water has been defined as, "any water where a canoe loaded with skins could float." Approval for any projects within navigable waters must be obtained from the Navigable Water Protection Officer of the Canadian Coast Guard.

Municipal Act of British Columbia

Some municipalities have enacted bylaws under the Municipal Act, to restrict alterations to local streams and watercourses in much the same manner as the provincial Water Act. These bylaws may require that approval to alter or improve a stream be obtained from the municipal engineering department or other designated authority.

Where habitat enhancement activities involve the use of provincial Crown Land, the proponent of a project should be aware that use of such land may be administered by one of three provincial agencies, depending on its classification or designation. Provincial forests, including land under Timber, Pulp or Tree Farm Licence, are administered by the Ministry of Forests. Provincial parks are administered by the Ministry of Parks. All other Crown lands fall under the jurisdiction of the Ministry of Crown Lands.

In the case of private land, permission of the owner is required to obtain right of trespass.

Even when all necessary government approvals and permits have been obtained, the project's proponent remains legally responsible for any resulting detrimental impact on private property, both upstream and downstream of the project. Under certain circumstances structures within or along a stream may also consti-

Legal Considerations

tute a hazard to the public. The project proponent may be liable for injuries or damages, to the public or adjacent property owners, that can be attributed to the project.

Project Approval

To assist in the review and approval of habitat enhancement proposals from the public, the Community Involvement Program has Community Advisors in many of the Department of Fisheries and Oceans district offices to provide technical assistance and to act as the point of contact with the public. A list of community advisors is provided at the end of this chapter. A group proposing a habitat enhancement project should first contact the Community Advisor, the local federal Fisheries Officer or provincial Conservation Officer. Once the contact has been established, the Community Advisor will assist the group in submitting their proposal. The proposal should clearly state the nature and location of the project, expected costs, and benefits. Project application forms are available from the local offices of the Department of Fisheries and Oceans and the B.C. Fish and Wildlife Branch.

On completion of the application the Community Advisor will guide it through the review process (Figure 2.1). The proposal will first be reviewed by both federal and provincial fisheries managers for its technical viability and compatibility with fishery and non-fishery activities within the area. Next, the proposal will be reviewed by Community Involvement Program managers to ensure that it is consistent with the overall management plan. If the project does not meet with approval at any stage, the Community Advisor will assist the sponsoring group in redrafting the application.

Once the project has been approved, the Community Advisor will continue to provide advice and assistance in implementing the project, and will keep other fisheries agency personnel informed as the project proceeds.

The approval process can be time consuming. To ensure approval prior to the designated work period, it is advised that the project proposal be submitted at least six months in advance of the proposed start-up date.

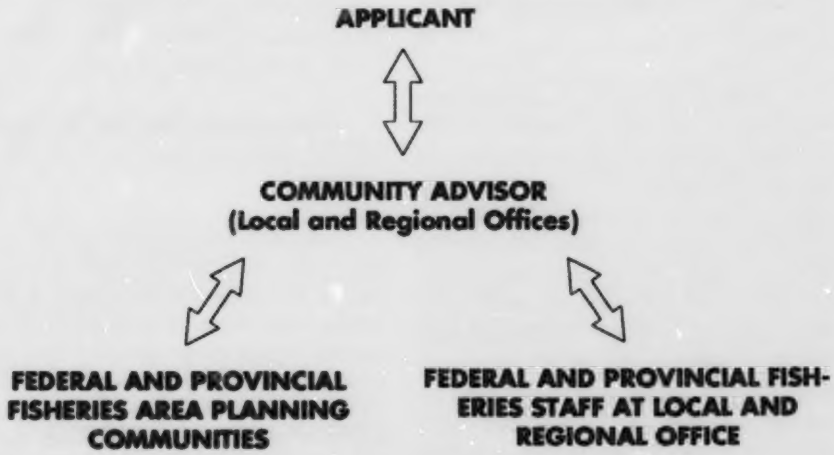

APPLICANT
COMMUNITY ADVISOR
(Local and Regional Offices)
FEDERAL AND PROVINCIAL FISHERIES AREA PLANNING COMMUNITIES
FEDERAL AND PROVINCIAL FISHERIES STAFF AT LOCAL AND REGIONAL OFFICE

Figure 2.1 Lines of communication in reviewing and approving salmonid enhancement projects initiated by the public.

Project Approval

Community Advisors

Queen Charlotte Islands

Tom Rutherford
Box 208
Queen Charlotte City, B.C.
V0T 1S0
559-4754

Northern Interior and North Coast Region

Barry Peters
4721B Lazelle Ave.
Terrace, B.C.
V9G 1R6
635-2206

Central Coast, from Cape Caution to Caamano Sound and east to Tatla Lake

Sandie MacLaurin
c/o Snootli Hatchery
Bella Coola, B.C.
V0T 1C0
982-2663

Northern Vancouver Island from Tsitka River on the east coast to Gold River on the west coast and from Knight's Inlet to Cape Caution on the mainland

George Bates
Box 10
Port Hardy, B.C.
V0N 2P0
949-6181

Central Portion, east coast of Vancouver Island, adjacent mainland inlets

Bryan Allen
148 Port Augusta St.
Comox, B.C.
V9N 7Z4
339-0431

Lower Vancouver Island south of the Cowichan River watershed

Trevor Morris
423-1230 Government St.
Victoria, B.C.
V8W 1Y3
388-0233

Central west coast of Vancouver Island, east to Nanaimo, south to Cowichan

Barry Cordocedo
69 Front St.
Nanaimo, B.C.
V9R 5H7
754-0303

Sunshine Coast and Howe Sound, Port Mellon to Desolation Sound

Grant McBain
Box 10
Madeira Park, B.C.
V0N 2H0
883-2613

Project Approval

North Shore, Howe Sound, Vancouver, Burrard Inlet

Gary Taccogna
610 Deruent Way
New Westminster, B.C.
V3M 5P8
666-0743

Coquitlam, Burnaby, north side of Fraser River to Lillooet

Maurice Coulter-Boisvert
610 Deruent Way
New Westminster, B.C.
V3M 5P8
666-2870

South side of Fraser River to Boston Bar

Joe Kambietz
610 Deruent Way
New Westminster, B.C.
V3M 5P8
666-0742

Central interior from Boston Bar to 100 Mile House

Dennis Demontier
1278 Dalhousie St.
Kamloops, B.C.
V2C 2G3
374-4322

Prince George, upper Fraser River and Yukon

Roy Argue
2392 Ospika Blvd.
Prince George, B.C.
V2N 3N5
561-5533

3 *Streambank Stabilization*

Introduction

Streams are active systems that undergo changes in their configurations from year to year. One of the primary processes that contributes to changes in a stream's course is streambank erosion (Figure 3.1). Erosion is also responsible for recruiting sediments and debris to the stream channel. Whether the effects of streambank erosion are beneficial or detrimental to fish habitat is largely dependant upon the type of materials being eroded. Streambanks that are comprised predominantly of gravels and coarser materials are good sources of spawning and rearing substrates. Conversely, streambanks that are made up predominantly of uncohesive sand, silts and finer sediments are sources of material that may adversely affect productive salmonid habitat. Streambank stabilization should therefore be restricted to streambanks that are comprised chiefly of sand or finer sediments in order to achieve a net benefit to the salmonid resource.

Streambank erosion occurs primarily during high flows and is most active on the outside banks of meander curves or bends in a stream. Sediments are transported away from the eroding bank and are deposited at some point downstream where the water velocity decreases and loses the energy required to transport the sediment any further. Large particles require the greatest amount of energy to transport and, therefore, are usually the first to settle out. Smaller particles are generally transported further downstream. This process permits a stream to crudely sort its streambed substrates. Streams that recruit excessive volumes of fine sediment may be incapable of transporting these materials through stream reaches that would otherwise be comprised predominantly of coarser substrates (ie: productive salmonid spawning and rearing habitat). Fines deposited in these areas fill the voids between the larger substrates, decreasing the subsurface flow of water to incubating salmonid eggs and/or smothering aquatic invertebrates. The fines may fill in pool areas and reduce available rearing area.

***Figure 3.1** An actively eroding streambank.*

Introduction

While streambank erosion is a naturally occurring process, it can be accelerated by some human activities. One example is clearcut timber harvesting which causes a significant increase in the magnitude of flood flows. The increased flows, in turn, contribute to increased streambank erosion.

Many approaches to streambank erosion control are available. Some are beneficial not only in controlling erosion, but also in creating rearing habitat such as pool cover. Streambank stabilization is commonly achieved through the placement of gabions or rip rap. Wing deflectors can also be used to provide bank protection; however, they are usually constructed for habitat complexing and pool creation. Wing deflectors are discussed in greater detail in Chapter 10. Other materials and methods that have been used to stabilize streambanks include log walls, timber cribs, concrete retaining walls, concrete loc-blocks and juniper boughs. Synthetic fabrics have also been employed for bank stabilization, although their long term success has yet to be evaluated.

Live vegetation should be used in conjunction with streambank stabilization techniques to prevent erosion of exposed soil surfaces. Plants and establishment techniques are discussed in Chapter 4.

Application

Before commencing any project involving the manipulation of stream habitat, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that must be consulted regarding the proposed project (Chapter 2).

Gabions

Gabions can be installed on slopes that exceed 1.5:1. Their use should be restricted to streams with low to moderate gradients and those that do not carry a high sediment load. Maximum water velocities against the gabions should not exceed 3.5 m/sec.

Rip rap

Bank slope should not exceed 1.5:1 for rip rap. Maximum water velocity is a function of rip rap size, but generally should not exceed 4.0 m/sec.

Design and Installation Guidelines

Prior to performing bank stabilization, the causes of erosion should be determined. Erosion is sometimes initiated or accelerated by upstream structures or obstructions that can be altered or removed at much less expense than proposed bank stabilization works. Consideration must also be given to potential increases in erosion at points downstream that may occur as a result of stabilization works. All potential effects of bank stabilization, both negative and positive, must be documented.

Streamflow records and a physical survey of the site can be used to determine peak water levels and velocities that proposed structures will have to withstand. Stabilization work should be conducted during the summer low flow period to minimize sedimentation and reduce impacts to fish and fish habitat.

Design and Installation Guidelines

Gabions

Gabion baskets are commercially manufactured from either plastic or heavy gauge galvanized metal. Due to their tendency to abrade and disintegrate, gabions are generally not recommended for use in coastal streams. However, they may be used for bank stabilization where the streambank is too steep for rip rap, or when suitable rip rap material is not readily available.

Gabions should be arranged to form a wall parallel to the stream channel. This minimizes the force of water and suspended bedload against them. To achieve the desired bank slope, gabions may be installed either one atop another, setting successive rows back towards the streambank (Figure 3.2), or on their side against the face of the streambank (Figure 3.3). The latter approach is preferable on higher banks, since the bank itself will support most of the weight of the upper gabions. Gabions should be installed to provide protection to a height of about one metre above the anticipated highest water level. Care must be taken not to reduce stream channel capacity through gabion placement, as this may cause overtopping of channel banks during storm flows, particularly on smaller streams.

Prior to site preparation, divert the streamflow away from the eroding bank. The eroding streambank can be graded to the desired slope and a trench excavated along the toe of the bank. The trench must be excavated to a point below the lowest level of anticipated scour. A seepage drain should be installed if water flows from the exposed streambank. The excavated area should be covered with a filter fabric to prevent fines from washing out from behind the gabions. Over top of the filter fabric, apply a bedding layer of coarse gravel and small rock. Gabions are in turn placed over top of the bedding layer, one row at a time, starting at the trench. They should be tied together with heavy gauge galvanized wire and anchored into the banks at the upstream and downstream ends. The baskets should be filled with angular rock larger than the gabion mesh openings (generally in the 100 - 200 mm range). Fill the gabions in layers so that no large voids are created. Such voids, especially near the bottom of the baskets, lead to deformation of the gabions and can ultimately lead to failure. Close and tie down the first row of gabions and repeat for additional rows. As necessary, backfill between the gabions and the streambank with gravel or small rock. A layer of topsoil can be placed behind the top row of gabions, and should be planted with a vegetative cover.

Rip rap

Rock rip rap is very durable and provides long-lasting protection against erosion. Its effectiveness is dependant upon the size, shape, and type of rock, and the slope, thickness and alignment of the rip rap layer. The rock must be hard (eg. granite) otherwise the bank will eventually fail. The rock must be angular, such as quarry rock, and of varying sizes so that smaller rocks fill the voids between the larger ones and effectively lock the rocks together. The size of rip rap that will be stable and effective is dependant upon the expected maximum water velocity against the rip rap. Figure 3.4 illustrates the relationship between water velocity and the median rip rap size required. The largest rocks should be placed at the toe of the bank. The rip rap should extend well above the level of the anticipated extreme flood. If the rip rap bank is constructed within the existing channel, the cross-sectional area of the channel will be reduced, thereby increasing the water level for any given flow. A typical rip rap section is illustrated in Figure 3.5.

Design and Installation Guidelines

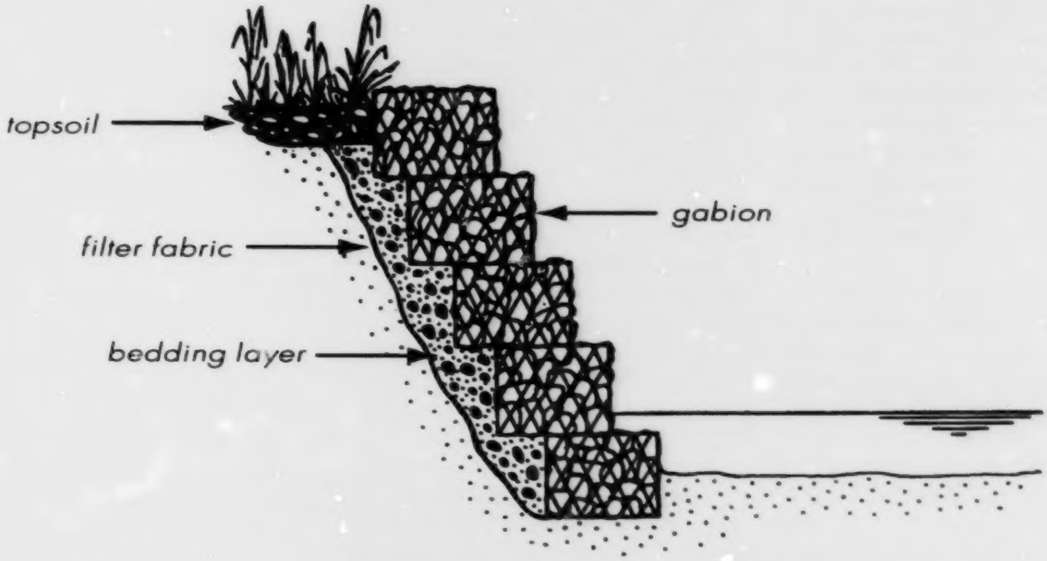

topsoil
gabion
filter fabric
bedding layer

Figure 3.2 Gabions offset to maintain bank slope.

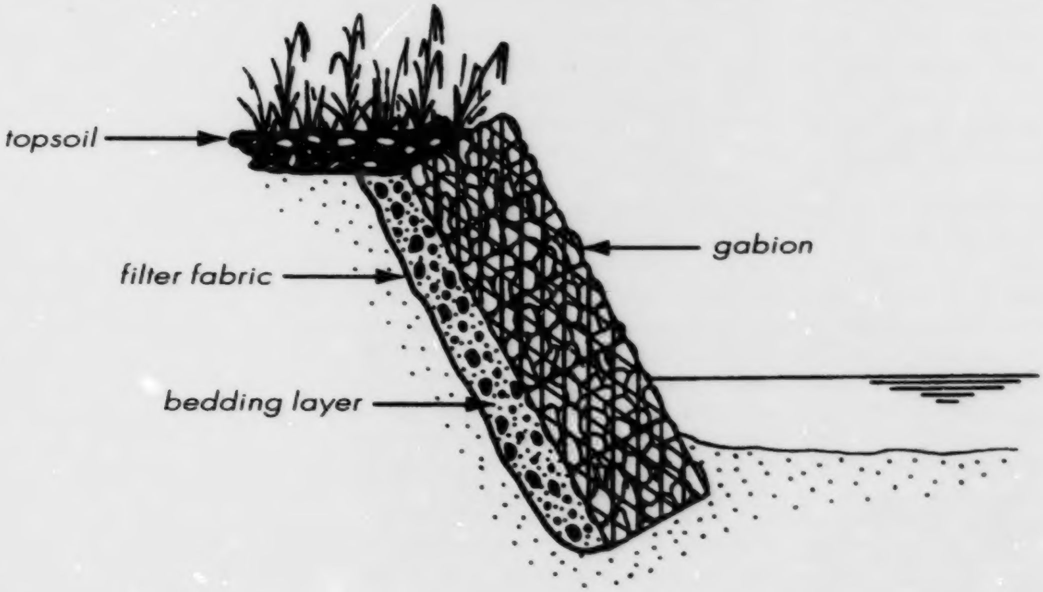
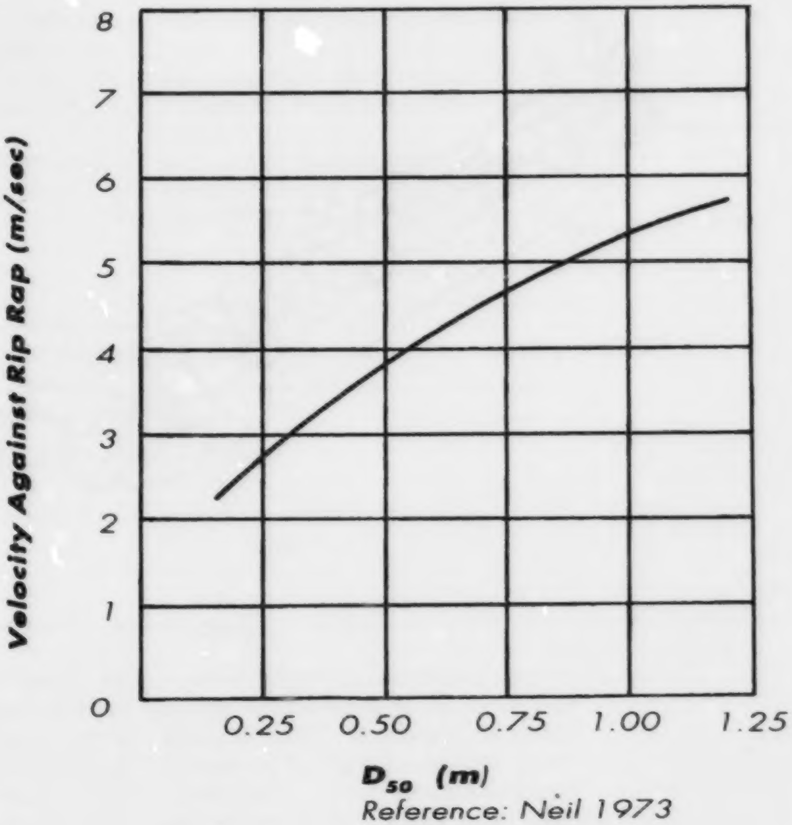

topsoil
gabion
filter fabric
bedding layer

Figure 3.3 Gabions installed flat against the streambank.

Design and Installation Guidelines



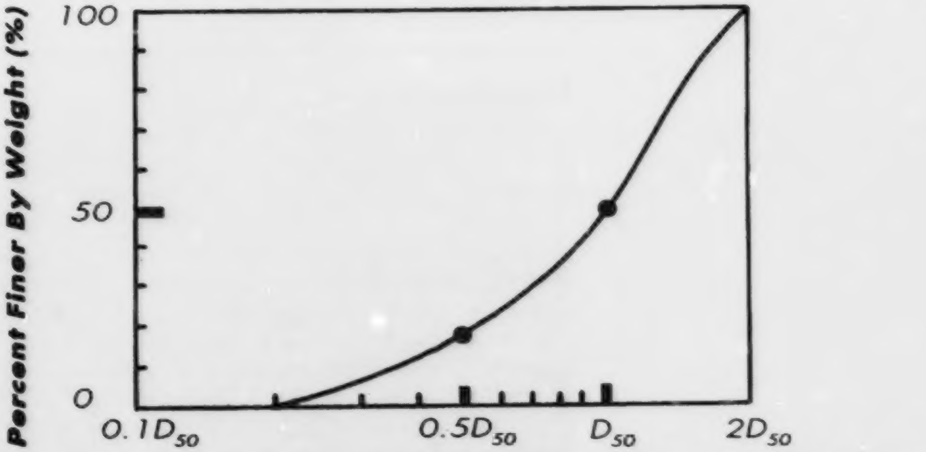


Figure 3.4 Rip rap design (adapted from Entrix Inc., 1986)

Design and Installation Guidelines

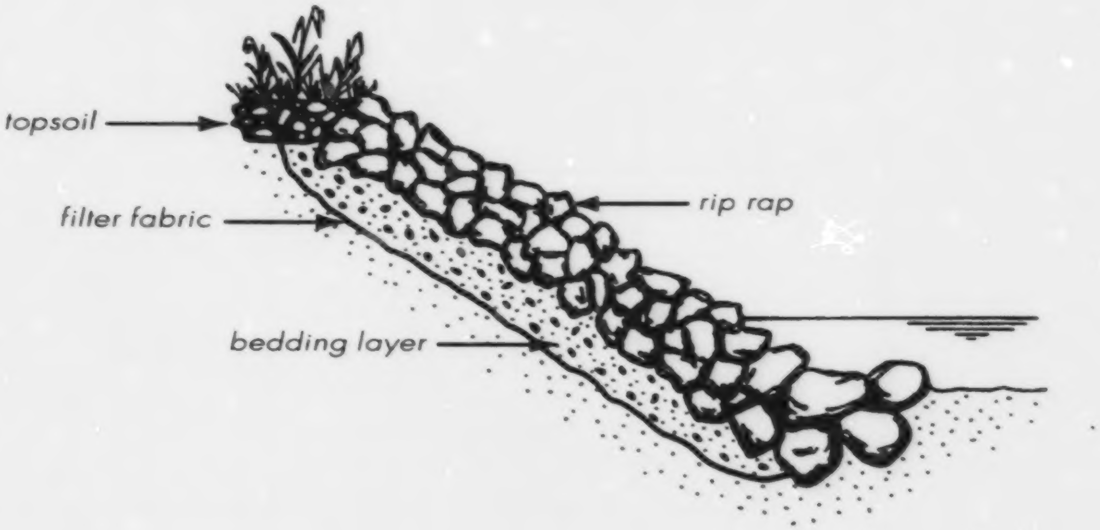


Figure 3.5 Rip rap bank protection.

Site preparation for rip rap installation is similar to steps as for gabion installation (see above). When installing the rip rap, place the largest boulders at the toe of the embankment in the trench. Place the remainder of the rip rap over the bedding layer. Plant vegetative cover on any remaining exposed soil surfaces. Some species (eg. willows) may take hold in the rip rap itself, particularly if soil is placed in the voids of the rip rap. This will add to the overall integrity of the structure. Figure 3.6 shows rip rap being placed on a graded streambank.

Maintenance

Gabions

Gabions should be inspected annually. Undermining may cause the gabions to sink and distort. Bedload movement may abrade the baskets or spread the basket openings, contributing to disintegration of the structure. Heavy gauge wire can be used to mend broken gabions. Erosion may occur at the upstream end of the gabion wall where it is keyed into the bank. This problem may be remedied by placement of additional bank protection.

Rip rap

Rip rap may be undermined, but will generally maintain its structural integrity. In extreme cases, additional rip rap can be added, otherwise, rip rap requires little upkeep.

Factors Influencing Cost

Gabions

- proximity and availability of suitable rock to fill the gabion baskets
- accessibility of the site to heavy machinery (dump trucks, front-end loaders, etc.)
- amount of site preparation required
- amount of work requiring heavy machinery
- labour intensive

Rip rap

- proximity and availability of suitable rock
- accessibility of the site to heavy machinery (dump trucks, front-end loaders, etc.)
- amount of site preparation required
- amount of work requiring heavy machinery

Advantages of Technique(s)

Gabions

- can be used to stabilize steep banks
- simple to construct

Rip rap

- stable at almost all flow levels
- very durable
- simple to install
- provide rearing habitat for juvenile salmonids

Figure 3.6 *Rip rap placement on the lower Fraser River.*

Disadvantages of Technique(s)

Gabions

- expensive and labour intensive
- usually requires the use of heavy machinery
- if undermined, difficult to re-establish the original structure
- baskets deteriorate due to abrasion and collision with bedload
- unnatural appearance

Rip rap

- requires heavy machinery for most phases of construction
- unnatural appearance if not used judiciously

Examples of Use

Gabions

Lower Mainland, B.C.: Gabions have been used extensively by developers and local governments in the Lower Mainland to control erosion on streams such as the Serpentine and Nicomekl rivers.

Rip rap

B.C. Spawning Channels: Rip rap is used in most spawning channels to provide stable banks. This is especially so for channels built to accommodate chum salmon that tend to undermine channel banks during redd construction.

Coquihalla and Coldwater rivers, B.C.: Keyed-in over-size rip rap was used during construction of the Coquihalla Highway to provide hydraulically rough channel margins that enhance to salmonid rearing habitat complexity.

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4 *Riparian Planting*

Introduction

The **riparian zone** is the area immediately adjacent to a stream or river, and is generally described in terms of its vegetative community. The contribution of a riparian zone to salmonid habitat is dependent upon the nature of the vegetation within the zone. A thriving riparian plant community regulates water temperature, controls erosion, and provides fish with cover and food. The densities of both juvenile and adult salmonids are influenced by the quality of the riparian zone.

The density of vegetative cover in the riparian zone affects the amount of sunlight that reaches the stream, and in turn influences water temperature. A dense vegetative cover overhanging a stream minimizes the potential for drastic increases in temperatures due to direct exposure to sunlight.

The roots of plants within the riparian zone consolidate streambank soils. The root mats of grasses and shrubs shield soils from surface erosion while the roots of larger trees help to maintain the structural integrity of the banks. Roots and organic debris also filter surface runoff, effectively removing suspended solids before they enter the stream channel.

The riparian zone is both a direct and indirect source of fish food. Terrestrial insect drop from overhanging vegetation provide fish with a direct source of food. Organic matter such as leaves and needles provide an indirect food source once they fall into the stream and are subsequently consumed by invertebrates which are in turn consumed by fish.

Vegetative cover also provides protection against predation for both juveniles and spawning adults.

This chapter presents techniques and considerations for the establishment of productive riparian plant communities. Target plant species, physical and biological prerequisites, propagation methods and site preparation are discussed.

Application

Before commencing any project involving the manipulation of riparian habitats, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be contacted regarding the proposed project (Chapter 2).

A qualified professional, preferably a botanist and/or horticulturist, should be consulted in all riparian planting projects. Much of the technology incorporated in riparian planting programs is borrowed from biotechnical slope design and horticultural practices. It is extremely important to consult qualified professionals in the planning, design, and application of riparian planting projects.

A riparian planting program is most effective where salmonid production is limited by high water temperatures, sedimentation from eroding streambanks, low food production and lack of protective cover.

The ideal candidate for riparian planting is a low to moderate gradient stream with a stable channel. Streambanks with slopes exceeding 1.5:1 (horizontal:vertical) may require structural stabilization prior to planting.

Streambank substrates will vary in the amount of organics (small woody debris as well as plant matter at various stages of decomposition) present. Organics allow for adequate drainage while retaining moisture and nutrients. Soils composed

Application

primarily of sand or clay are not well suited for plant establishment. Sandy soils have poor water and nutrient retention properties. Soils composed primarily of clay exhibit poor drainage and tend to consolidate into a hard, compact substrate that deters penetration by plant roots. In general, the higher the composition of organics, the greater the potential for successful plant establishment.

Design and Installation Guidelines

Site Preparation

Site preparation may be required for a successful vegetative community to become established. Necessary works may include slope grading, streambank protection, soil placement and/or installation of sediment traps.

Slopes may have to be graded to decrease the potential for erosion. Decreasing the gradient of a slope increases its stability. In general, streambanks should not have slopes steeper than 2:1 (horizontal:vertical).

Streambank protection is often a prerequisite to riparian planting where unstable banks occur. Rip rap (broken quarry rock) is the most common and effective material for bank stabilization. Gabions (rock filled wire baskets) are also often used. Planting is performed in those areas immediately above the bank protection works in order to maximize overhang cover. Streambank stabilization using these materials is discussed in detail in Chapter 3.

Where existing soils are unsuitable for plant growth, or where additional material is required to back-fill voids between the existing bank and bank protection works, topsoil may have to be brought in. It is critical that substrates provide the proper rooting medium for those plant species selected for planting.

Soil fertility varies with different substrate types. Fertilizers may be required where substantial organic substrates are lacking. The three major elements in fertilizers are nitrogen (N) , phosphorus (P), and potassium (K). It is often nitrogen that is the limiting nutrient within many riparian habitats. It is used in large quantities by plants, is consumed by many soil-borne organisms and is easily lost by the leaching action of rainfall. Nitrogen primarily comes from decomposing organic matter. Phosphorous and potassium are present in the mineral particles of most soils, and are therefore rarely limiting.

Often fertilizer packages will display a symbol such as 10-8-6. This symbol represents the percentage composition of nitrogen, phosphorous and potassium respectively (i.e. N-P-K). For the purpose of riparian enhancement projects, (where fertilization is needed), the fertilizer should have a high nitrogen content.

Care must be taken when applying fertilizers near streams, particularly those with low flows. Surface runoff from lands treated with fertilizers may contribute to **eutrophic** conditions in the stream which in turn may degrade fish habitat quality. Fertilizers should be used only where little or no fertilizer loading into adjacent watercourses will occur.

Physically altering riparian slopes will cause some erosion of slope material. A sediment trap downhill and downstream of such sites may be necessary. The most appropriate trap to use, due to its ease of installation and low cost, is a brush barrier. Brush barriers are effective at any location where sediment in surface water requires

Design and Installation Guidelines

filtering. They are especially effective at the toe of recently modified slopes (Figure 4.1).

Brush barriers filter surface runoff by reducing the flow velocity and trapping sediment in the branches and limbs of the brush pile. Material requirements include anchor logs and brush not exceeding 15 cm in diameter and 4 m in length. Stumps should not be used.

The large anchor logs are placed at the toe of the slope and secured to stumps, trees and/or rocks. The brush is then placed at the toe of the slope above the anchor log. The brush is compacted and embedded into the ground by tamping with a "Hi-Hoe" or backhoe bucket in order to prevent water from flowing under it.

Vegetative Components

Plant Species

It is not unusual to find wide variation in substrate type and moisture within riparian soils. Plants must be adapted to the soil conditions present at the proposed enhancement site. Potential saturation of riparian soils can be predicted from data on seasonal water level fluctuation documentation. Visual inspection of soils, and comparison with adjacent soils and the vegetative communities that they support, can determine the suitability of the soils for different plant species.

The following recommendations apply in the selection of plant species for use in riparian habitat enhancement projects:

- select plant species of known fish habitat value
- select plants species known for substrate stabilization
- select perennial plant species
- select plant species that have been used successfully in the past; preferably native species that will grow and develop into a plant community that strongly resembles natural riparian communities within the project area

A list of common, native, woody plant species is presented in Appendix 3. Reference is made to the habitats and taxonomically distinguishing features of each species. Included are **propagule** types for individual species..

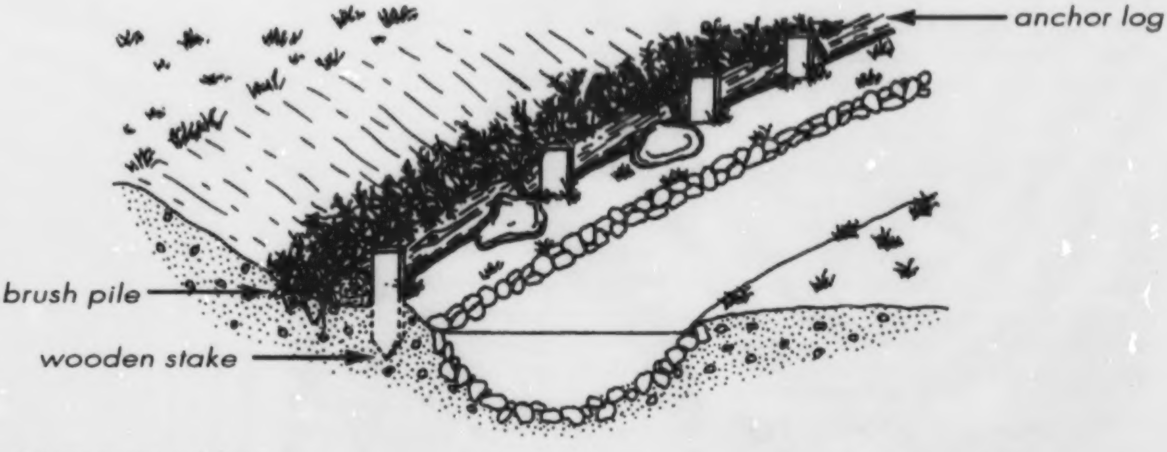

Figure 4.1 Brush barriers at toe of slope.

Design and Installation Guidelines

Plant Propagules and Planting

Plant propagule selection for riparian habitat enhancement involves consideration of the following factors:

- plant species selected
- propagule availability
- cost
- seasonal timing

Commonly used propagule types include seeds, sods, cuttings, and transplant and nursery stock. Seeds and sods usually involve grasses and legumes. Cuttings, transplant stock and nursery stock generally refer to woody plant species.

Seeds

The simplest and most effective approach to controlling soil loss from exposed surfaces is to establish a healthy mat of grasses and legumes. Grasses and legumes bind soil particles, limiting erosion and **soil creep** until shrubs and trees can become firmly established. Seeding of small areas can be accomplished by hand broadcasting . Large areas are more effectively treated through hydroseeding (Figure 4.2). Hydroseeding is the mechanical application of a wet slurry of seeds, fertilizers and mulches. Mulches provide an excellent growing medium for seeds and minimize seed loss due to wind, rainfall and surface runoff. The best time to seed is usually during the spring and fall when temperatures, moisture and sunlight are optimal for germination.

Erosion fibre mats can be incorporated in seeding programs to enhance substrate stability and hold seeds in place until young plants become established. Fibre mats are manufactured from both synthetic and organic materials, and can be purchased with seed mixtures already incorporated into the matting.

Sods

Sods can be used to provide an "instantaneous" ground cover during periods of the year when environmental conditions are not favourable for plant establishment via seeding. Sods offer a quick remedy for bare soil surfaces exhibiting erosion.

Sods are commercially available and tend to be relatively expensive. They are usually composed of only one grass species, which can be problematic if the environmental conditions are not suitable for that particular species. An alternative to commercial sod is "harvested" sod from nearby fallow agricultural fields. Fields in the immediate area of the project site will exhibit a similar physical environment. Fallow fields are colonized by grasses and herbs tolerant to prevalent environmental conditions.

The harvesting strategy must minimize sediment loading from harvest sites into local water courses. Harvest sods from natural depressions within the field, where the moisture regime most closely resembles that of the riparian area. Harvest sods from several small patches rather than a single large area (e.g. checker board pattern).

Sod harvesting can be accomplished with a "Hi-Hoe" or backhoe using a bucket without teeth. Sod placement can be done by the excavator, however, manual assistance is often required to precisely place sod material.

Cuttings

There are three basic types of cuttings commonly used for propagation (Figure 4.3). A normal cutting will root easily for the majority of riparian shrub species. For species with large piths, a **heel** or **mallet** may improve rooting response.

Design and Installation Guidelines

Figure 4.2 Hydroseeding a manipulated slope.

Normal cuttings are typically pruned stems or shoots with no required accessory features. As with all cuttings, a sharp pair of sheers is essential for making clean cuts. Dull sheers bruise plant tissues. These damaged tissues are more susceptible to disease and rot, conditions that compromise the viability of the cutting.

A heel cutting is a young side shoot that is stripped away from the main stem so that a thin sliver of bark and wood (heel) from the main stem accompanies the side shoot. The heel gives the cutting a firm base that protects it from possible rot.

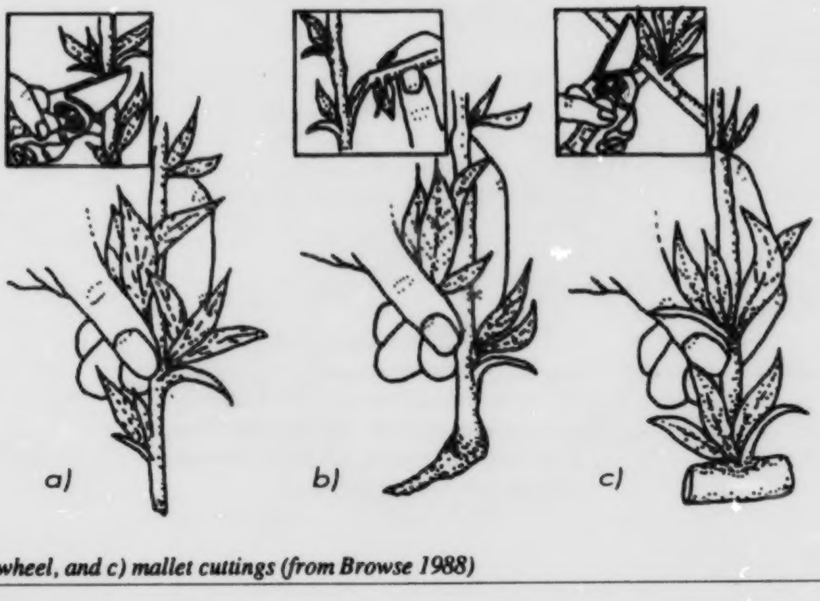

Figure 4.3 a) normal b) wheel, and c) mallet cuttings (from Browse 1988)

Design and Installation Guidelines

Mallet cuttings are similar to heel cuttings, but incorporate more of the main stem than a heel cutting. Mallet cuttings should be taken from new stems late in the growing season. Cut horizontally across the parent stem immediately above a suitable side-shoot. The cut should be made as close to the side-shoot as possible to prevent die-back and subsequent rotting. Make a second horizontal cut about 2 cm below the top cut so that the side-shoot is isolated with a small "mallet" of main stem.

The type of wood used for cuttings varies with different plant species and the type of cutting selected. Cuttings are categorized according to the age of the wood.

Softwood is the most immature part of the stem and has the highest capacity to develop roots. However, cuttings made of this wood type also exhibit the highest mortality. Softwood cuttings are taken in the spring from the fast-growing tips of plants. They are very susceptible to water loss through newly emerged leaves. Even a small amount of water loss will hinder root development. By the time the leaves on a cutting are wilting, all root development will have ceased and the cutting will die.

Greenwood cuttings are taken from the soft tip of the stem after the spring flush of growth has slowed down. The stem is slightly harder and woodier than softwood cuttings. Greenwood cuttings have a reduced ability to develop roots. Take cuttings early in the morning from a fully **turgid** stem that has reached the seasons' growth potential. Immediately place the cutting in a bucket of water or a polyethylene bag in a shaded location to prevent water loss. Water loss hinders root establishment.

Semi-ripe cuttings are those taken at the end of the growing season in late summer. They are thicker and harder than softwood cuttings and are therefore hardier, but are still susceptible to the problems of water loss since they possess leaves. Semi-ripe cuttings can be taken from a main stem that has reached the seasons' growth potential or from the side-shoots. Remove the tip of the stem if it is soft and fleshy, but leave it if the **apical** bud has hardened and growth has ceased for the year.

Hardwood cuttings are probably the easiest type of cutting to work with in habitat creation projects. A hardwood cutting is made during the dormant season from the fully mature stem of a deciduous tree or shrub. Since there are no leaves, the potential for water loss is minimal. A stem grows at different rates throughout the season, developing fastest in spring then slowing until autumn when growth ceases altogether. The base of a stem produced in the previous spring has the greatest potential to develop roots and should be used for most hardwood cuttings. Hardwood cuttings can be taken any time during the dormant season, but they will be most successful at "leaf fall" and just before the leaf buds break. Rooting success is lowest during the early spring.

Normal and heel cuttings can be taken from softwood, greenwood, semi-ripe and hardwood stems. Mallet cuttings are restricted to semi-ripe and hardwood cuttings.

The application of rooting hormones to cuttings can enhance root development. The most common and best suited rooting hormone is beta-indolyl-butyric acid (IBA). Softwoods and greenwoods are treated with 0.2 % IBA. Semi-ripe and hardwoods are treated with 0.4 % IBA.

Cuttings may be live-staked or wrapped together to form wattles. Live-staking involves the insertion of cuttings end first into the soil. Wattles are bundles of cuttings that are laid side by side in

Design and Installation Guidelines

shallow trenches and covered with soil (Figure 4.4). The bundles consist of woody plant stems, preferably of a species that will root easily.

Stakes

Preparation and Handling of Stakes

Select healthy wood that is reasonably straight. Make clean cuts with un-split ends. Stems up to 4 cm in diameter can best be cut with two-handled brush pruning shears. Larger branches can be cut with a Swede saw or small chain saw. The lower end of the cutting may be sharpened and pointed . Trim branches from cuttings as close to the main axis of the stem as possible.

In general, the thicker the cutting, the greater the food reserves for growth. Cuttings greater than 2.5 cm in diameter are preferred for staking, but may be limited by availability of native material. Cuttings should be at least 45 cm long and be cut so that a **terminal bud scar** is within 2.5 to 10.0 cm of the top. The greatest concentration of healthy shoots occur immediately below an **annual ring** (formed from a terminal bud scar).

Cuttings must not be allowed to dry out. They are best planted the same day as prepared. They must be kept covered and moist during transport, storage, and during the planting operation. Cuttings may be kept submerged in water for one to several days, however, excessive wet storage will promote rot. At no time should cuttings be left exposed to the air to dry out.

Planting Stakes

Plant the cuttings with the oldest part of the cutting in the ground. It is preferable that at least 80 percent of the length of the cutting be planted in the ground. Deep planting minimizes water loss. Avoid damaging or stripping the bark or bruising the stakes when setting them in the ground. Bruising of tissues and bark removal promotes rot. In fairly soft soil the stakes can be driven with a wooden maul. Do not use an axe or sledge hammer as this will cause

Figure 4.4 Typical wattle and anchor stakes.

considerable physical damage to the stake. In hard ground use an iron bar or star drill to prepare the holes for the cuttings. Tamp the soil around the cutting so that it is firmly in the ground and cannot be easily moved or pulled out. No more that 5 cm of the cutting should be exposed after planting. Work should proceed from the top of the slope to the bottom to avoid burying the cuttings completely. Rows of cuttings across a slope should be staggered to enhance bank stability.

Wattles

Preparation and Handling of Wattles

Cuttings of 1.25 cm in diameter or larger, are bundled together to form a wattle. Two people are required to assemble and tie the wattles. The number of stems varies with the size and species of plant material. The crew places the required number of cuttings in the bundle, alternating butt ends. When compressed and tightly tied, the bundles should be 10-15 cm in diameter, and should taper at each end (cigar shaped). Tying is accomplished by one person holding and compressing the bundle while the second person ties the bundle with two or more loops of binders' twine or heavier material. Ties are placed 30-40 cm apart using non-slipping knots. Wattles should not be prepared more than 2 days prior to use. They must kept moist.

Planting Wattles

Trenches should not be excavated until the wattles are ready to plant. This precaution will prevent exposed soils from drying out. The trench should be shallow, about half the diameter of the bundles. The wattles are held in place on the downhill side of the trenches with stakes that are driven through the bundles at a maximum spacing of 45 cm. Two stakes should be used for each bundle overlap and should be placed near the bundle ties.

Stakes may be made of several materials. Live stakes have the advantage of rooting and adding to the plant cover, however, they are harder to drive in than other types of stakes due to their flexibility and softness. Stakes made from cut lumber are available in several lengths and widths from commercial lumber outlets. Steel reinforcing bars (rebar) may also be used for staking in hard substrates. When rebar is used, the wattles can be secured by either bending the rebar over the wattle or by tying the wattles directly to the rebar.

Proper covering of wattles is a critical component of a successful wattling operation. Soil is brought down the slope and worked into the spaces of the wattles. A fringe of material, approximately 10 percent of the bundle volume, should remain exposed. If too much of the wattle is exposed the cuttings will dry out and die. Covered wattles can be walked over top of to compact and work the soil into the bundles, however, care must be taken not to damage the cuttings.

Transplants and Nursery Stock

Woody plants may be established by transplanting native shrubs and trees to the enhancement site. Prior to transplanting, an inventory of available stock in surrounding habitats should be made to ensure donor stock is available in sufficient quantity.

If heavy machinery is available, and donor stock is readily accessible, the donor stock may simply be excavated with a large proportion of the root mass and native soil attached and transplanted to the recipient site. In those instances where heavy machinery is not available donor material may be transplanted bare root or ball and burlapped.

Bare root transplants, (where shrubs and small trees are excavated, transported and planted without native soil surrounding the root), should only be performed

Design and Installation Guidelines

during late winter, before the buds have become swollen. The roots must be kept moist to minimize physiological shock.

Balling and burlapping involves excavating a large proportion of the root mass and associated soil and wrapping it in burlap cloth. Although best performed during late winter, it can be performed at any time of the year if done carefully. The balls (roots and soil) should be solid and wrapped tightly with 142 g jute burlap. Balls up to 50 cm in diameter may be dug up and wrapped without the support of heavy twine or rope. Double burlap (142 g) may be used on balls of 50-60 cm in diameter in lieu of twine. Balls 60 cm and larger in diameter should be drum laced at 20 cm spacing using 6 mm rope. In general, the root ball diameter should be at least ten times the **caliper** of the shrub or tree, or 50 percent of the height of the material for plants less than 1 m in height and 30 percent of the height of material for individuals 1-3 m in height.

Nursery stock is often the most convenient propagule for planting. Many nurseries grow native species well suited to riparian environments. Contact nurseries well before the proposed project start-up date to ensure that stocks are adequate for the project.

Tools used in planting include dibbles, spades, spuds, and small hand picks . The choice of tools depends on the size of plant to be planted and existing substrates. Dibbles are useful for small plants in soft but cohesive soils, but are not recommended for use in very sandy or hard soils. Spuds are useful for small plants in hard rocky soils, while small hand picks are particularly useful on steep slopes where footing is difficult. Spades and shovels are required for larger plants.

Planting Guidelines

Planting is best done during the late winter or early spring when the plants are still dormant, or during mid spring or late fall when conditions are cool and wet. Excessive drying of plant material must be avoided.

Divide both the plants and the project area into manageable units to avoid over planting some sections at the expense of under planting others. Space the plants according to potential rates of growth and maximum size attainable. Avoid linear alignments of shrubs and trees. Staggering plants up and down the bank presents a more natural appearance and increases habitat complexity.

Excavate holes where the shrubs and trees are to be planted. The holes should be of sufficient size and depth so that root systems of containerized plants are not disturbed, and those of bare-root nursery plants and transplants are not folded or bent during planting. Work should proceed rapidly so that planting holes do not dry out. Plants should be placed in the hole and the roots covered immediately. Large shrubs and small trees can be transported to the project site with a "Hi-Hoe" or backhoe excavator. Plants should be tamped firmly in place and watered immediately.

Use marker stakes to locate small plants that may be overgrown during the first few seasons. Where necessary, provide protection from animals that may trample, eat or otherwise damage the plants. Wire screen can be used around each plant, or where grazing livestock are present, fencing may be required (see Chapter 5).

Maintenance

Planted material should be monitored regularly during the first two years after planting. Monitoring of riparian planting sites will determine whether a maintenance program is required.

Irrigation and fertilization are necessary when excessive drying of substrates or nutrient deficiencies (yellowing of leaves) are observed. Herbaceous perennials such as grasses are removed if they are smother young woody plants. Extensive grazing by cattle, deer or other animals is rectified by fencing the affected area. The project site should not require maintenance for more than two years. By that time the plants should have become well established in their new environment.

Factors Influencing Cost

General

- area to be planted
- amount of site preparation required
- heavy machinery costs (if required)
- cost of non-vegetative materials (e.g. rip rap)
- costs of maintenance, irrigation, fertilization and fencing (if required)

Seeds

- the amount and mixture of seed, mulch and fertilizer
- application technique (hand broadcasting versus hydroseeding)
- erosion matting (if required)

Sods

- species of grass in commercial sod
- proximity of fallow agricultural field if "harvesting"
- heavy machinery costs (if "harvesting")

Cuttings

- proximity of native material
- propagation technique

Transplants

- proximity of native material
- size of transplant material; larger trees may require mechanical tree extractor

Nursery Stock

- number of plants; per unit cost may decrease with large orders
- species of plants
- size/age of plants; the cost of plants is related to cultivation time; prices are usually based on the height of the plant or the size of pot
- availability of plants; nurseries are reluctant to grow many native plant species on speculation, therefore, stocks are not consistent; shipping costs may be incurred for transporting plants from distant nurseries

Advantages of Technique(s)

Seeding

- technically very simple
- very effective technique for reducing soil loss from slopes, especially when used in conjunction with erosion fibre mats
- hydroseeding permits the simultaneous application of seed, mulch and fertilizer

Advantages of Technique(s)

Sod

- immediate protection of exposed soil surfaces

Cuttings

- success rates of greater than 90% with more desirable species such as willow and red osier dogwood
- material can be obtained from native stock within the immediate area; species are adapted to prevalent environmental conditions

Transplants

- material can be obtained from native stock within the immediate area; species are adapted to prevalent environmental conditions
- large specimens can be used to provide mature cover

Nursery Stock

- containerized stock makes for ease of handling
- large specimens can be used to provide immediate overhanging cover

Disadvantages of Technique(s)

Seeding

- soil stability is not fully achieved until grasses and legumes become established
- grass and legume seedlings are very vulnerable to drought
- if intense rains occur prior to germination, much of the seed may be washed away
- herbivory by insects, birds and small mammals can be extensive

Sods

- commercially available sod material is expensive
- heavy machinery is required to transplant sod

Cuttings

- summer cuttings exhibit shock, full recovery will not take place until the following growing season
- location of sites with adequate donor material may be time consuming, particularly for large project areas

Transplants

- heavy machinery is required to transplant large shrubs and trees
- location of sites with adequate donor material may be time consuming, particularly for large project areas

Nursery Stock

- the availability of nursery stock, particularly for less common species, is not consistent
- many nurseries will grow material to order, however, this process may require one to two years lead time

Examples of Use

Seeding

Enns Creek, Matsqui, B.C.: A commercial seed mix (Buckerfield's M-H Pasture Mix) was applied manually over steep, barren streambanks along a diverted section of the creek in 1989. Coconut/straw erosion mats were applied on sidecast earth mounds and subsequently seeded. Reed canary grass seed was hand broadcast in the lower areas of the stream channel adjacent to the water's edge. The commercial mix exhibited rapid germination and growth, however, the reed canary grass failed to become established by late fall.

Hydroseeding/Stakes

Coldwater River, Larson Hill, B.C.: In 1987, hydroseeding was performed along the banks of a network of "finger ponds" that were excavated to provide coho salmon rearing and spawning habitat. The objective was to stabilize the recently excavated substrates. The banks were also live-staked with willow and red osier dogwood.

Most of the grasses became established but later died. Only low stakes (nearest the water) survived. Lack of success at this site was attributed to poor substrates (fast draining sand, gravel and cobble) and variable water levels. This project exemplifies the need to thoroughly assess all site conditions prior to planting.

Sods/Transplants

Compensation Creek, Surrey, B.C.: This small tributary to Bear Creek was structurally altered in late summer of 1988. A straight channel was converted into a meandering channel, increasing the streams length by three times. Sidecast earth mounds were overlaid with sod excavated from an adjacent fallow field (Figure 4.5). Three to four meter tall alder trees were transplanted to the mounds using a "Hi-hoe" excavator. By the summer of 1989, the sods and trees were well established and were indistinguishable from neighbouring natural stands of vegetation.

Figure 4.5 Compensation Creek, Surrey, B.C. Application of harvested sod, 8 months after transplant

Examples of Use

Wattles/Nursery Stock/Seeding

Coho Creek, Maple Ridge, B.C.: During the late winter/early spring of 1990, a steep cut bank along a diverted section of the creek was planted and stabilized with wattles. Wattles were made from willows and red osier dogwood cuttings. Nursery stock was used to vegetate gentler slopes. Over 400 one gallon potted shrubs (red osier dogwood, snowberry and ninebark) were planted. Exposed soil surfaces were seeded by hand with Buckerfield's M-H Pasture Mix.

Chilliwack Wing-Dyke, Fraser River, Chilliwack, B.C.: During late winter/early spring in 1990, 500 meters of dyke was planted with willow and red osier dogwood wattles. The wattles were planted in a prepared trough filled with soil. A tentative monitoring program will assess plant survival and growth.

Tynehead Creek, Surrey, B.C.: Riparian planting was undertaken in conjunction with streambank fencing at three sites on Tynehead Creek, a tributary of the Serpentine River. Two sites were planted with elderberry, ninebark, hardhack, red osier dogwood and cottonwood. Preliminary results indicate that all of the plants have become established. A third site was planted with sandbar willow, red osier dogwood, thimbleberry, salmonberry, wild rose, mountain ash and douglas fir. Preliminary results also indicate high survival.

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5 *Streambank Fencing*

Introduction

Streambank fencing, also referred to as exclusion fencing, is a technique for dealing with livestock related impacts in and adjacent to streams. Livestock are attracted to streams by water and lush vegetation of the **riparian zone**. The presence of livestock, even if only periodic, occurs at the expense of the stream's fisheries resource.

Livestock grazing affects riparian vegetation, channel morphology, water quality and streambank structure. Riparian vegetation is often reduced or eliminated. Changes in substrate composition, channel widening and infilling of pools due to trampling and sediment loading transform channel morphology. Water quality may be degraded by increased temperatures attributable to the loss of shading caused by the removal of riparian vegetation. Dissolved oxygen levels may be depressed due to increased water temperature and/or nutrient loading. Both temperature and nutrient loading contribute to an increase of algal and bacterial **blooms** that in turn increase the **biological oxygen demand**. Streambank structure is altered through trampling which contributes to sloughing and accelerated soil erosion.

Various grazing and ranging strategies have been devised to improve riparian habitats impacted by livestock. Many of these strategies are based on rest-rotation, in which grazing periods are scheduled between seasons of recovery. In terms of habitat improvement and protection, a superior approach is total exclusion of grazing animals from stream areas. This can be achieved through streambank fencing. On open rangeland rest-rotation may be the only economically viable option since the cost of fencing great lengths of stream is very often prohibitive. However, where the impact of livestock grazing is limited to relatively short sections of productive stream, construction of fences along the banks can result in significant improvement in both riparian and instream habitat, while still allowing livestock to graze the adjacent lands.

Fencing is a relatively expensive habitat enhancement technique. Costs should be justifiable in terms of potential increases in fish production, therefore, emphasis should be on productive stream sections such as spawning areas.

Since many livestock-fishery conflicts occur on private land, the approval and cooperation of landowners is an important issue which should be dealt with at the planning stage. Landowners have some genuine concerns regarding the construction of fences on their property, such as loss of grazing area and establishment of undesirable plants (e.g. blackberries). Others may need to be convinced that there is a problem and that it is attributable to their livestock. Although the cost of the fence will usually be borne by the project agency, the landowner should formally agree to maintain the fence for a specified period of time. The landowner should also agree to leave the vegetation within the fenced area undisturbed. If the landowner is willing, a restrictive covenant can be registered against the title of his/her property, ensuring that the specified greenstrip of land remains undisturbed in perpetuity.

Once streambank fences are erected, degraded streams will regain their natural characteristics. Some changes will occur quickly while others may take many years. The re-establishment of vegetation may be accelerated by planting native species of grasses, shrubs and trees (see Chapter 4). Figure 5.1 shows an undisturbed stream environment. In contrast, Figure 5.2 shows a section of stream degraded by livestock grazing and trampling.

Introduction

Figure 5.1 An undisturbed stream with productive aquatic and riparian zones.

Figure 5.2 Stream degraded by livestock.

Application

Before commencing any streambank fencing project, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

Application

A formal agreement should be reached with the landowner, (whether private or public), to authorize fence construction and address responsibility for long term maintenance.

Fencing can be employed on streams with low to moderate gradient channels and minimal lateral shifting. Streams susceptible to debris-laden floods are poor candidates. Debris torrents will damage fences, especially where they cross the stream.

Design and Installation Guidelines

Fences should conform to agricultural standards, with allowances for crossing and watering points. In most cases barbed wire fencing can be used, although there are three alternative types of fence commonly used. Page wire is used where animals other than cattle are to be excluded. Wooden fences may be required where horses are the livestock of concern, but are much more expensive than barbed wire. Electric fences are sometimes used, but require a power source and frequent maintenance. Since costs and maintenance requirements are primary considerations in stream enhancement efforts, only barbed wire and page wire fences are discussed here. Design considerations for barbed wire and page wire fences are provided in Figure 5.3.

Fences should be set back far enough from the top of the stream's bank to provide for unhindered growth of vegetation and allow for some lateral movement of the channel. The labourer should participate in placing marker stakes in order to avoid any disagreement regarding their location.

When scheduling fence construction attempt to avoid periods when the ground is either wet or frozen. Other guidelines for fence construction include the following:

- try to maintain as straight a fence-line as possible as this simplifies construction and minimizes costs
- if any clearing is necessary cut as little vegetation as possible
- anchor, corner and stretch posts must be wood, but line posts may be steel. Use pressure-treated wood or galvanized steel posts. Wood posts treated with chromated copper arsenate (CCA) to CSA standard 080 are recommended as they are paintable and safer to handle than those treated with other preservatives
- watering and crossing points must be constructed so that livestock cannot enter the fenced-off area. Fences can be built directly across most streams but the lowest fence wire should be above the highest water level. On streams with highly variable water levels an adjustable swing gate (Figure 5.4) can be used to pass floodwater and debris while preventing livestock from moving along the stream channel at low flows
- livestock watering and crossing areas should be constructed to minimize sedimentation. Coarse gravel placed on all accessible bed and bank areas will provide protection against erosion. Precast concrete and barn floor slats have also been used successfully to prevent erosion at livestock access points. The entry and exit ramps of crossings should have gradients which do not exceed 10:1 (horizontal:vertical) to provide acceptable footing for livestock and safe passage of machinery.

Design and Installation Guidelines

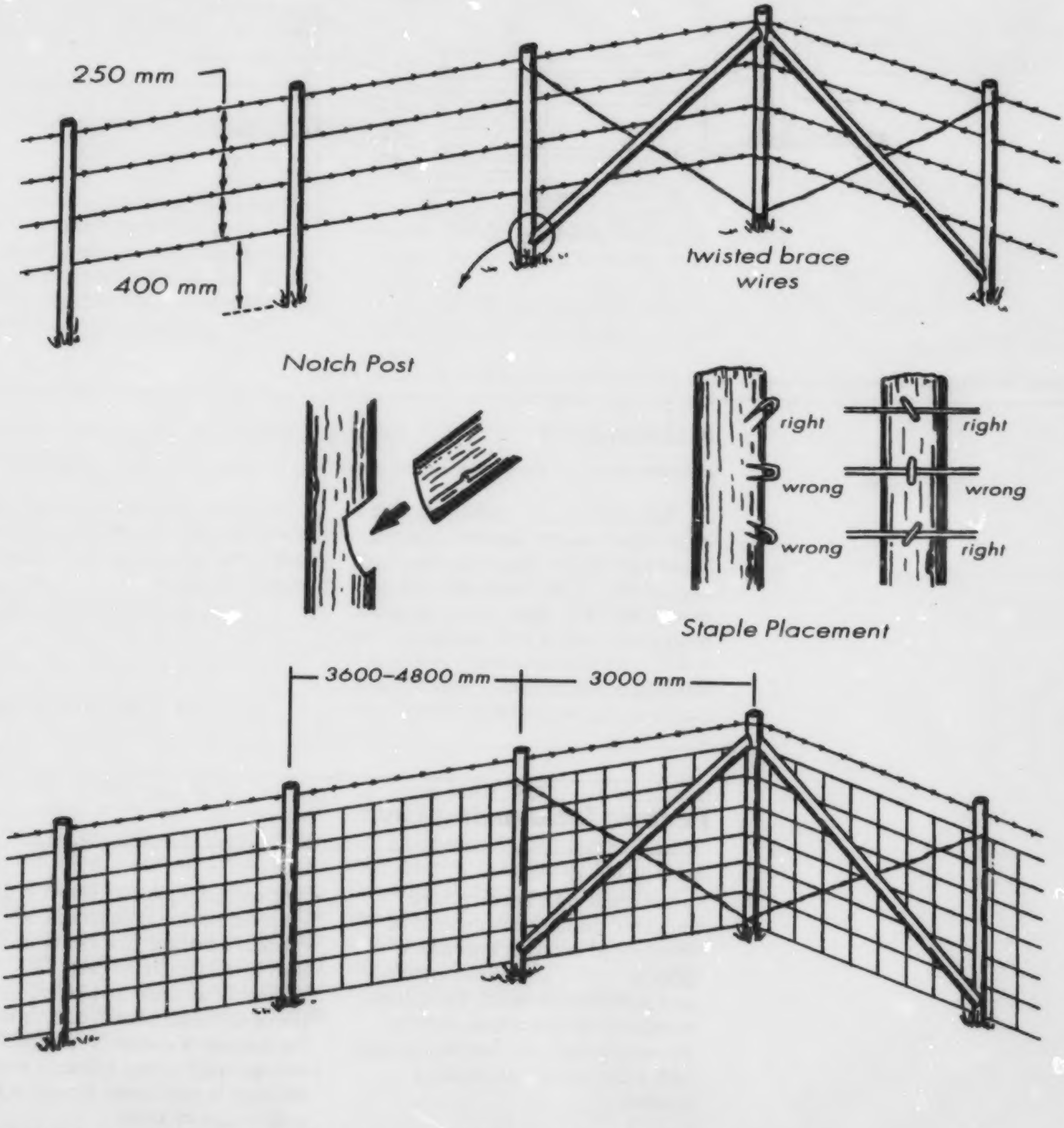
250 mm
400 mm
twisted brace wires
Notch Post
right
wrong
wrong
right
wrong
right
Staple Placement
3600–4800 mm
3000 mm

***Figure 5.3** Construction specifications for barbed wire fences (top) and page wire fences (bottom).*

Design and Installation Guidelines

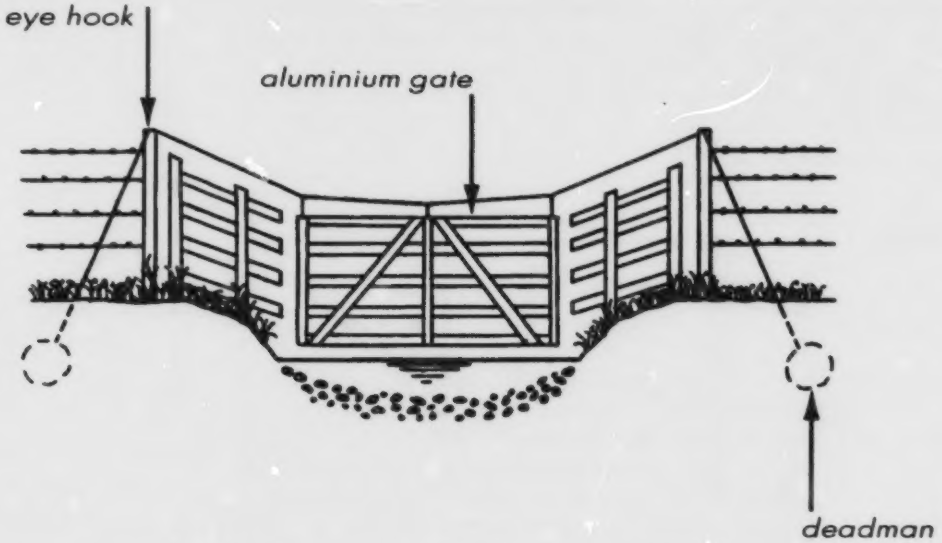

Figure 5.4 Adjustable swing gate used at livestock crossings (adapted form Reichard, 1984).

Maintenance

Fences built to normal agricultural standards should require very little maintenance during the first ten years. Trees that fall across the fence should be removed and any slack wires should be restretched. Debris that may accumulate on the fence, particularly at crossings and watering points, should be removed as it increases drag on the fence during flooding.

Long term maintenance may include replacement of some sections which are undercut by the stream, or loosened by frost heaving or flooding.

Factors Influencing Cost

- when erecting fences on private property, the landowner should be encouraged to obtain legal advice prior to signing any agreements such as a restrictive covenant; the agency proposing the streambank fencing project may wish to cover the costs of such a consultation as an act of goodwill
- fencing cost is directly related to the length of stream to be fenced, its configuration, and whether or not both banks require fencing; the number of watering and/or crossing points will affect project cost, as will the number of corners in the fence
- site accessibility may influence cost, although in most cases this will not be a significant problem

Factors Influencing Cost

- posts can be driven into the ground either manually or with a tractor-mounted post pounder; unless volunteer labour is available or the length of fence is short, the tractor- mounted post pounder will usually be more cost effective
- where horses are the livestock of concern, landowners may insist on wooden post-and-rail fencing; wood fencing may increase the cost of fencing by 2 to 3 times

Advantages of Technique(s)

- fences are quite durable and should require very little maintenance
- where livestock graze, fencing is the most effective means of rehabilitating damaged streambeds and banks while still allowing access for livestock
- the stream/riparian zone within the fenced area will recover naturally, without any additional enhancement structures
- the buffer strip that becomes established will attract and benefit terrestrial wildlife

Disadvantages of Technique(s)

- fencing costs can be high, especially for long, meandering streams
- crossing and/or watering points may be expensive if excavation or bank protection work is required
- if an alternative livestock watering source is required, pumps and a water conveyance system may be necessary
- recovery of some stream characteristics may be very slow

Examples of Use

Lower Mainland, B.C.: Fences were installed along seven streams (Serpentine River, Salmon River, Little Campbell River, Clayburn Creek, Atchelitz Creek, Salwein Creek and Nathan Creek) (Figures 5.5 and 5.6). To preserve integrity and exclude livestock, preliminary assessments conducted between one and two years after fencing indicate improvements in habitat quality and juvenile salmonid densities.

Loon Lake, B.C.: A four-strand barbed wire fence was constructed along two kilometres of Loon Creek, the main inlet stream to Loon Lake (Clinton, B.C.). Degradation of spawning habitat by cattle was cited as the reason for a decline in the success of lake anglers, therefore, a fence was constructed to improve trout spawning conditions within the creek.

Examples of Use

Figure 5.5 Barbed wire fence on the upper Serpentine River, Surrey, B.C.

Figure 5.6 Wooden post and rail fence constructed on a tributary of the Salmon River, Langley, B.C.

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6 *Gravel Catchment and Placement*

Introduction

Substrate composition in a stream reflects various hydrologic, hydraulic and geologic conditions present throughout the year. Although streambed material is continuously being moved downstream, the composition at any given location generally remains unchanged from year to year. Bed material that is washed away is replaced by material of similar composition.

Spawning salmonids require a minimum area of suitable gravel to build a **redd** (Table 1). The area available will determine the number of fish that can spawn in any given section of stream. When spawner numbers exceed stream capacity, late spawning fish may damage the redds of earlier spawners. In exceptionally crowded circumstances, fish may die before spawning.

Where spawning habitat has been identified as the limiting factor, salmonid production can be improved by increasing the quality and quantity of available spawning habitat. This may be accomplished by installing instream structures to trap gravels of appropriate size, or by adding clean, sorted gravel to the streambed. Gradient controlling devices may be required to stabilize newly placed material.

***Table 1** Average area of salmonid redds and area recommended per spawning pair in channels (Reiser and Bjornn, 1979).*

Fish Species	Average area of redd (m^2)	Area recommended per spawning pair (m^2)
Spring chinook	3.3	13.4
Fall chinook	5.1	20.1
Summer chinook	5.1	20.1
Coho	2.8	11.7
Chum	2.3	9.2
Sockeye	1.8	6.7
Pink	0.6 - 0.9	0.6
Steelhead	4.4 - 5.4	-
Rainbow	0.2	-
Cutthroat	0.09 - 0.9	-

Application

Before commencing any project involving the construction of instream structures or the placement of gravels, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

For this technique to be of value, insufficient spawning area must be the factor limiting salmonid production. For stream rearing species, sufficient rearing habitat must be available to support increased fry production.

Application

A hydraulic engineer or other experienced professional should be consulted regarding the design and placement of instream structures and/or gravel. Knowledge of the hydraulic environment is essential to project success. Hydraulic criteria suitable for spawning habitat is presented in Table 2. Gradients greater than 1.5% are generally unsuitable for gravel recruitment projects.

Gravel Catchment

Gravel catchment devices will function only in streams that recruit and transport large volumes of gravel. Ideal candidate streams are those with adequate bedload but insufficient instream structures to stabilize substrates. The stream section to be enhanced should be stable and relatively straight.

Gravel Placement

Gravel placement is appropriate in a stream section that meets hydraulic criteria suitable to retain gravels, but lacks a natural source of gravel (e.g. a stream reach downstream of a lake or reservoir). Project success is greatest where streamflows are relatively stable. Streams with unstable flows, or those that experience extreme flooding, will require the use of catchment devices to stabilize the gravel.

Table 2 Water depth, velocity and substrate size criteria for salmonids (Reiser and Bjornn, 1979).

Fish Species	Minimum Depth (m)	Velocity (m/s)	Substrate Size (mm)
Fall chinook	0.24	0.30 - 0.91	13 - 102
Spring chinook	0.24	0.30 - 0.91	13 - 102
Summer chinook	0.30	0.32 - 1.09	13 - 102
Chum	0.18	0.46 - 1.01	13 - 102
Coho	0.18	0.30 - 0.91	13 - 102
Pink	0.15	0.21 - 1.01	13 - 102
Sockeye	0.15	0.21 - 1.01	13 - 102
Steelhead	0.24	0.40 - 0.91	6 - 102
Cutthroat	0.06	0.11 - 0.72	6 - 102

Design and Installation Guidelines

All instream work should be conducted during the summer when flows and salmonid utilization of the stream are their lowest.

Gravel Catchment

Catchment structures alter the hydraulic characteristics of the stream in such a way that substrates of a particular size are selectively deposited and maintained. Project managers should be experienced in predicting the location of scour and deposition in order to ensure project success.

Design and Installation Guidelines

Structures should be located at riffles or the tail end of pools, preferably where the channel is 30% to 50% wider than the mean channel width. Structures may either fully span or partially span a stream channel.

Full Spanning Structures

The simplest form of a full spanning gravel catchment device is an invert control weir installed perpendicular to the flow. Gravels accumulate both upstream and downstream of the structure (Figure 6.1). For stability, invert controls weirs should be installed at least 0.3 metres below the streambed. In larger streams the plunge pool below the weir should be armoured with large rock to prevent undermining of the weir. Sloping the downstream face of the weir by constructing it in layers, with the bottom layer further downstream than the top layer, will force water away from the structure and minimize undermining (see Chapter 10, Figure 10.1). The abutments at each end of the weir should be well armoured with rip rap to at least 0.6 metres above flood levels to prevent bank erosion.

Invert controls should be constructed with large rock. In the past, rock filled gabions have been used since they are permeable and contribute to good intragravel flow upstream of the weir. However, gabions are not recommended for use on coastal streams as they tend to deteriorate and collapse. Weirs constructed of large rock have achieved good success, and are aesthetically superior due to their natural appearance.

When constructing an invert control, large pieces of rock, preferably square or angular, are carefully placed side by side across the stream to concentrate the flow (at low discharge) towards several notches in the weir, permitting fish passage. In small streams with stable flow (e.g. lake outlets) weirs can be constructed with logs or wooden planks.

Full spanning structures constructed diagonally across a stream channel provide greater stability and more diverse habitat for salmonids. Three variations are recommended: the diagonal; the "V"; and the "Y" (Figure 6.2). The diagonal, which is installed between 20 and 45 degrees from the downstream bank, is the simplest to install, most stable and the only design that functions on curved stream sections. The "V" is simple to install and is stable, but requires some bank protection. The "Y" is stable, but is the most complex to construct. In large streams, these structures should be constructed using large angular rock; in small streams, rock or logs may be used.

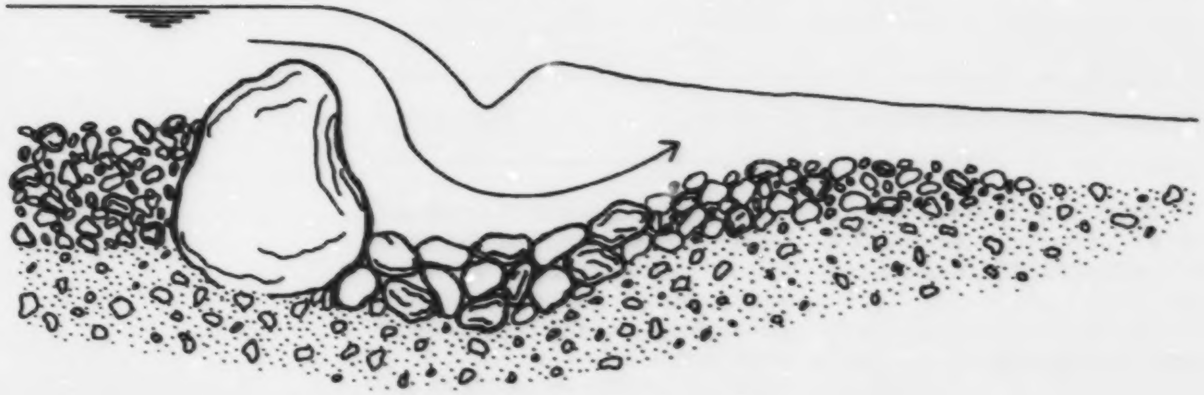

Figure 6.1 Gravel accumulation upstream and downstream of a weir.

Design and Installation Guidelines

Increased efficiency is achieved by constructing structures in pairs, separated by a distance of about 1.5 times the wetted width. The top of the downstream structure should align with the vertical midpoint of the upstream structure.

Partial Spanning Structures

Deflectors and boulder groups are the primary types of partial spanning structures. They are simpler alternatives to full spanning structures, but are often used in conjunction with full spanning structures to create greater habitat diversity. Most partial spanning structures create both rearing and spawning habitat by scouring pools and accumulating gravel.

Deflectors

Deflectors are designed to redirect the flow of water to create areas of scour and deposition. They can be installed either adjoining streambanks or entirely within the wetted stream area. In either case the deflector should not span more than 1/3 of the wetted stream width. Large angular rock is the most suitable construction material. Deflectors, whether located adjoining the streambank or mid-channel, should be installed at 20 to 45 degrees from the direction of flow. Mid-channel deflectors should be constructed in a "V" formation. Successful deflector designs are shown in Figure 6.3.

Boulder Groups

Large rocks located within the wetted stream area cause localized scour and deposition that in turn creates both rearing and spawning habitat (Figure 6.4). These formations are quite simple to construct and, providing the hydraulic environment is well understood, tend to be very stable.

Gravel Placement

The absence of suitable spawning substrates is not always due to the inability of the stream to stabilize material, but is sometimes a result of a lack of appropriate material that can be recruited to the channel. For example, there is virtually no supply of coarse sediments to a stream reach immediately downstream of a lake or reservoir, and with regulation of flow and removal of bedload by the lake, outlet streams have little or no means of acquiring new substrate material. Groundwater-fed channels likewise have little opportunity to recruit new substrates. Placement of clean, sorted gravels can bring an otherwise unused stream section into production (Figure 6.5). High quality spawning gravels are loose and tend to be unstable, therefore, gravel placement should be accompanied by installation of control features (e.g. invert control weirs) to ensure that newly added gravel is not washed away. In general, spawning substrates should be consist of about eighty percent 10 to 50 mm gravel with the remaining twenty percent up to 100 mm gravel. Salmonids may avoid imported, processed gravel, preferring to wait until it has been "aged". If available, use native gravels that can be screened from stream deposits.

Design and Installation Guidelines

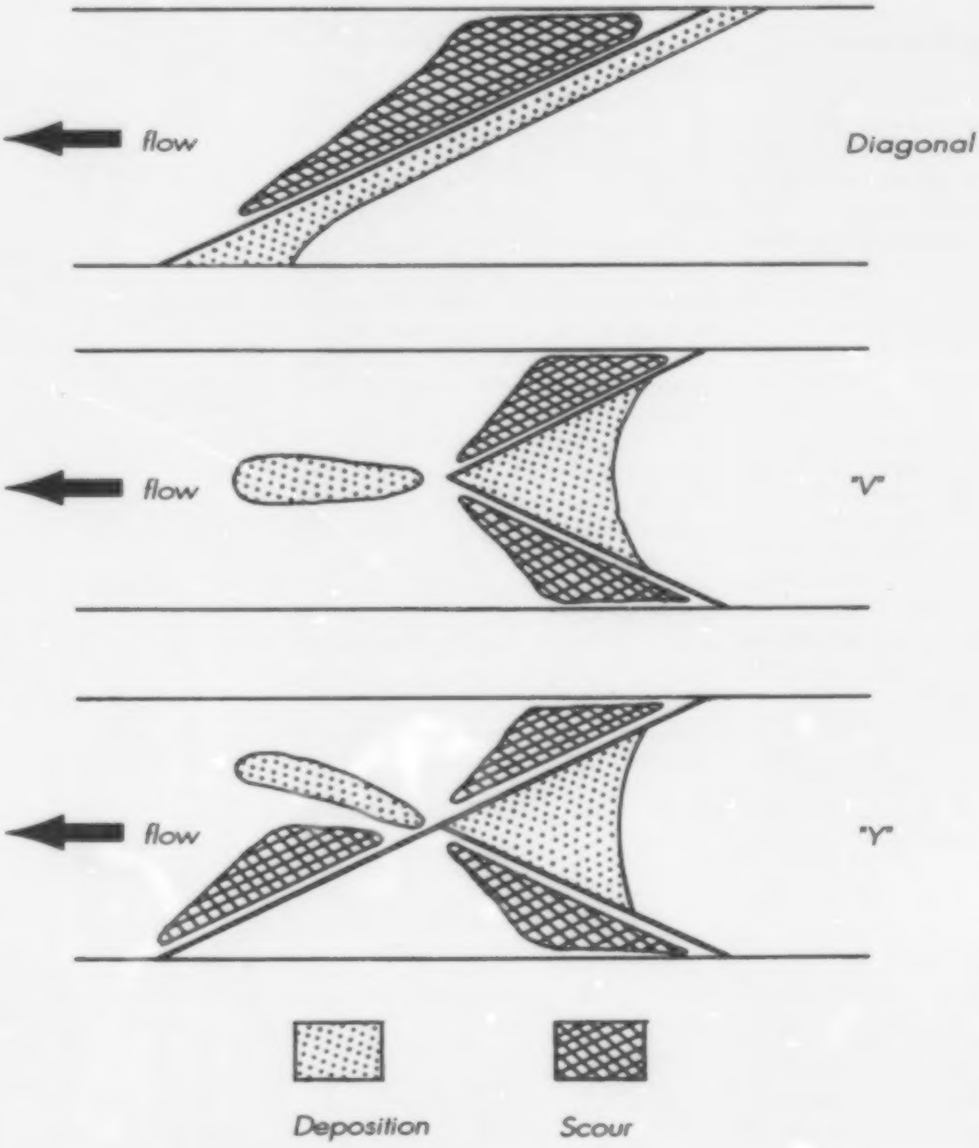
flow
Diagonal
flow
"V"
flow
"Y"
Deposition
Scour

***Figure 6.2** Scour and deposition associated with full spanning structures.*

Design and Installation Guidelines

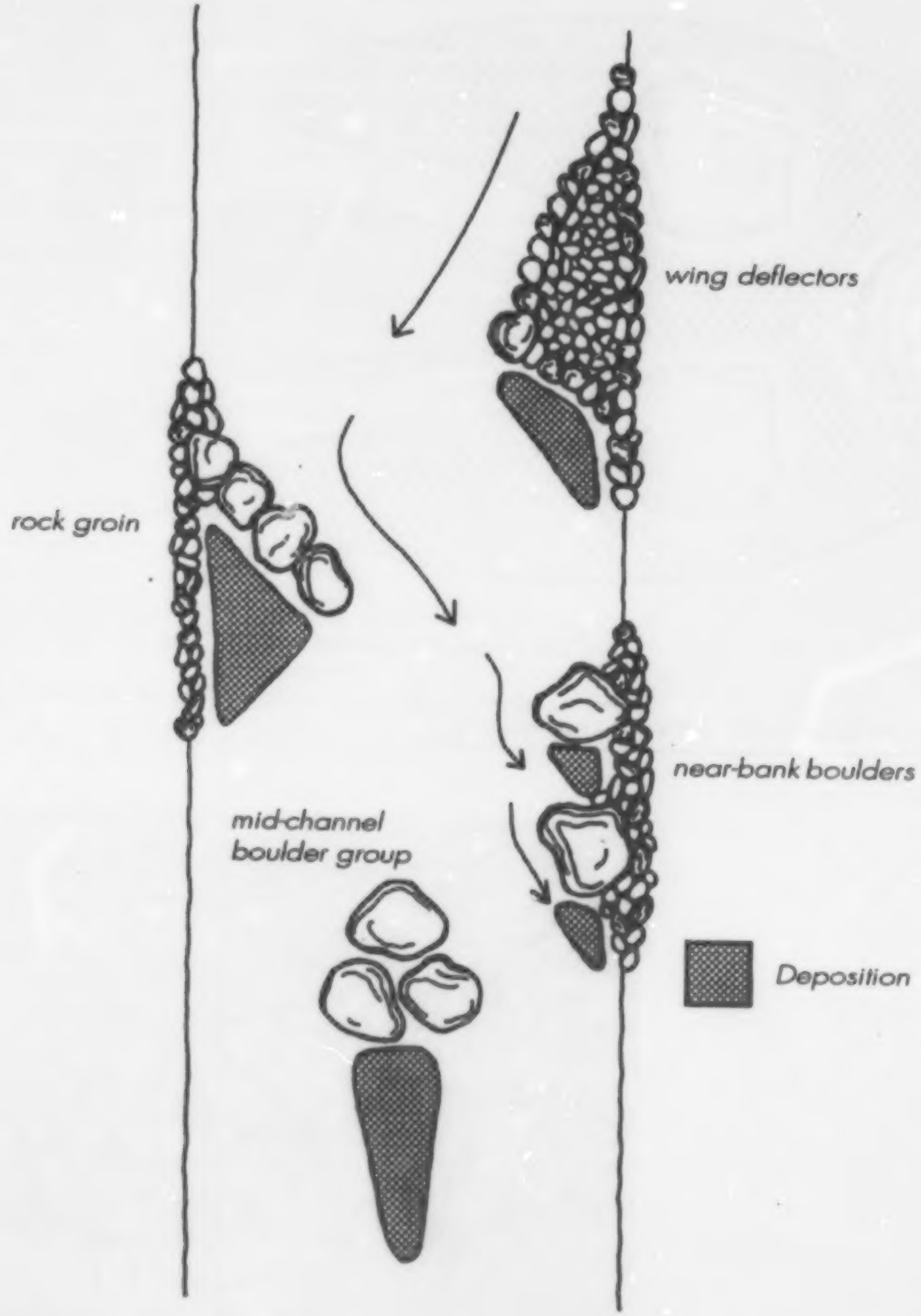
wing deflectors
rock groin
near-bank boulders
mid-channel boulder group
Deposition

Figure 6.3 Deflector designs.

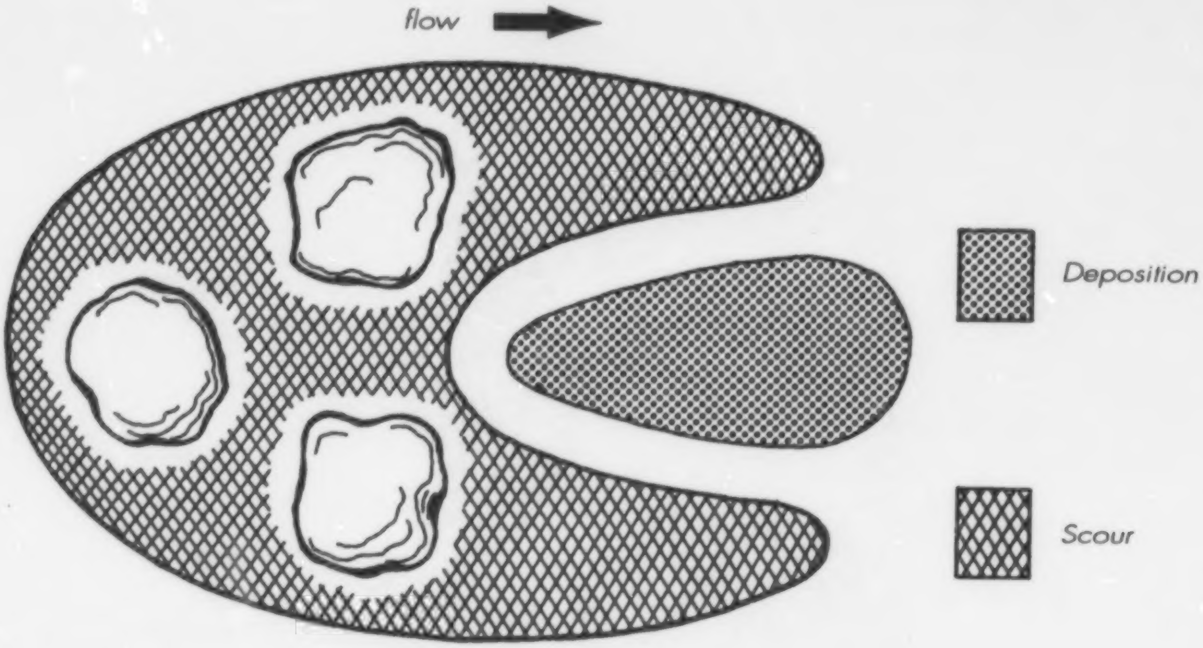
flow
Deposition
Scour

Figure 6.4 Scour and deposition associated with a boulder group.

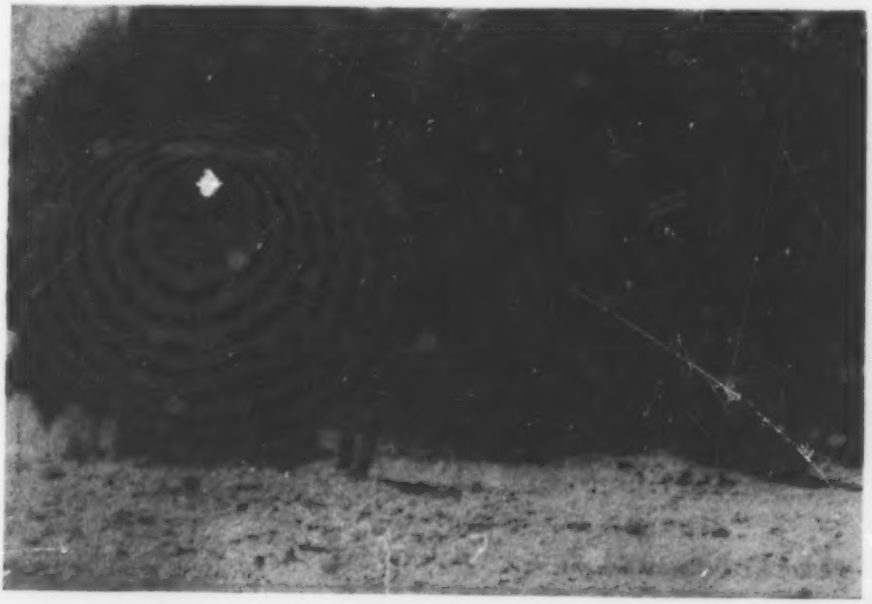

Figure 6.5 Placement of suitably sized spawning substrates in a new channel.

Maintenance

Catchment devices should be monitored to ensure that they are performing as designed. In the case of poorly functioning rock weirs, there may be little that can be done short of rebuilding the structures. The abutments should be checked for signs of erosion, and if found, remedied by the placement of additional rip rap. If catchment devices are found to be stable but not trapping adequate spawning gravels, placement of spawning gravels might be considered.

Placed gravels that show signs of downstream transport should be stabilized by installing catchment structures. Gravel that is stable but silt laden should be cleaned (see Chapter 7).

Factors Influencing Cost

- accessibility of the site to heavy machinery
- labour and heavy machinery costs
- availability and cost of suitable material for control structures and/or spawning gravels

Advantages of Techniques(s)

- natural materials (rocks and logs) maintain the aesthetic quality of the stream
- rearing habitat (pools, turbulence, etc.) is also created by most structures; riffles created by catchment structures increase the production of aquatic invertebrates, the primary food of salmonids
- placed spawning substrates are free of undesired fines; egg -to-fry survival rates increase

Disadvantages of Technique(s)

- in coastal streams, substantial planning and design efforts are required to develop stable structures that will produce the desired affects
- periodic maintenance is required to ensure that structures and gravels remain stable
- despite the best efforts of qualified project staff, some projects fail to significantly increase salmonid production (e.g. stable gravel bars may be established, fish may choose not to use them)

Examples of Use

Gravel Catchment

Queen Charlotte Islands, B.C.: Two gravel catchment designs were used to improve habitat on four streams on the Queen Charlotte Islands degraded by mass wasting. A single log structure installed perpendicular to the flow was found to produce better spawning and rearing habitat than a multiple log (log arch) structure. The single log design was much more simple and less costly to construct.

Gravel Placement

Thompson River near Walhachin, B.C.: Gravel was placed on 1,300 m^2 of streambed to an average depth of 0.74 metres. All gravels except for an area of approximately 240 m^2 were washed away by the following year. Loss of gravel was attributed to use of material that was not coarse enough to remain in place.

Chilliwack River, B.C.: The B.C. Ministry of Environment placed gravels in the outlet of Chilliwack Lake to improves spawning habitats. The gravel has subsequently been used by spawning chinook salmon and steelhead trout. Gravel placed in tributaries of the Chilliwack River has also been used by spawning salmonids.

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7 *Gravel Cleaning*

Introduction

Salmonid eggs require a continuous flow of cool, well oxygenated water during incubation to support embryo development and remove metabolic wastes.

The rate at which water is moved into and through the gravel is dependant upon gravel permeability, depth and velocity of streamflow, and shape and gradient of the channel. Permeability is a function of the substrate composition, and declines as the percentage of fines in the gravel increases. Fine sediments such as sand and silt fill **interstitial** spaces in the gravel and reduce subsurface flow rate. Fines also increase the consolidation of substrates, making it difficult for spawning fish to excavate **redds**.

Spawning salmonids tend to build redds in shallow riffles, where intragravel flow is greatest. The shape of the redd accentuates the flow of water downwards into the gravel (Figure 7.1). Although some fines are washed away in the process of redd building, gravels in the redd are generally of the same quality as those of the surrounding streambed. Where stream substrates contain high fractions of fines, intragravel flow rates may be low and contribute to high egg mortalities. Fines that accumulate on the streambed after egg deposition impede fry emergence from the gravel. Although the flow of water through the gravel is negligible in comparison to surface flow, a rate of only 100 centimetres per hour is generally sufficient for high survival of eggs to the fry stage. The mortality of incubating eggs may increase in substrates with only 10 percent fines.

Natural spawning substrates are rarely free of fine material. Where fines constitute a large fraction of spawning substrates, gravel cleaning may significantly improve egg-to-fry survivorship. Cleaning gravel will alter benthic community structure. Invertebrates which inhabit cobble, riffle substrates, such as mayflies and some species of caddisflies, may exploit new interstitial spaces, while other invertebrates that inhabit fine sediments, such as chironomid larvae, may decline in number.

Spawning gravels can be cleaned either by mechanical scarification or hydraulic flushing. This chapter discusses these techniques and presents planning considerations for gravel cleaning projects.

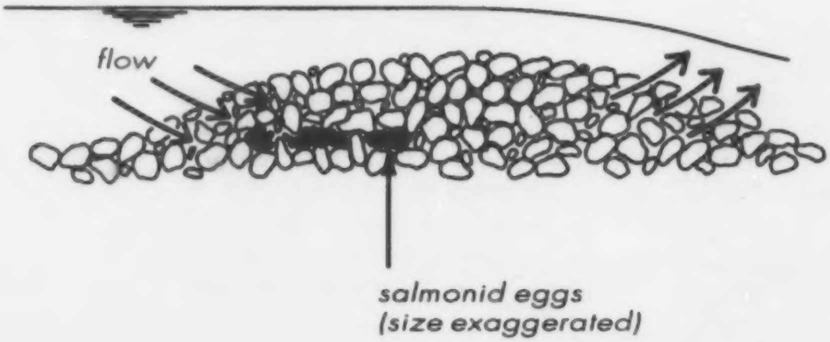

Figure 7.1 Cross-section through a redd.

Application

Before commencing any gravel cleaning project, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

Gravel cleaning, particularly by mechanical means, may cause hydraulic changes in the stream channel. For these reasons, a qualified and experienced engineer or hydrologist should supervise gravel cleaning operations.

Gravel cleaning is employed primarily in artificial spawning channels, where sediment input and flows are regulated. It has limited application in natural streams because of the potential for downstream siltation and the short term benefits provided. Its use in natural streams should be restricted to sites where streamflows are stable and sediment loads are low (e.g. lake outlet streams).

Instream work should not be conducted during spawning, incubation or critical juvenile rearing periods. Cleaning should be conducted during periods of moderate to high streamflow when all spawning substrates will be within the wetted stream area and when higher water velocities will promote sorting of the substrates and downstream movement of fines.

Design and Installation Guidelines

Mechanical Scarification

Scarification involves excavating the streambed and exposing the substrates to the flushing effect of the stream. Finer sediments are entrained in the flow and carried away while coarser materials settle back to the streambed. Work begins at the upper end of the spawning area and proceeds downstream. A sediment basin can be excavated in the stream to collect fines that wash downstream.

Bulldozing

The blade of a bulldozer can be used to lift substrates up and turn them into the current. The machinery should cross the stream facing upstream at an angle of 45 degrees from the channel banks. After each pass, the bulldozer moves downstream and returns to the starting bank with the blade raised (no turning of gravel), then repeats the procedure from a point two or three metres further downstream (Figure 7.2). Each successive pass allows the fines which accumulate in front of the bulldozer to be removed. The bulldozer should enter the stream in such as manner as to minimize bank damage and loss of riparian habitat. Care should also be taken to ensure that no motor oil, fuel or lubricants enter the stream.

Velocity Segregation

An excavator with a large bucket can be used to lift substrates out of the stream and slowly drop them back into fast flowing water, to segregate the substrates and flush out the fines. This technique is disadvantageous in that it creates considerable turbidity downstream.

Vibrating Bucket

This technique lessens the discharge of fines into the stream. A large excavator bucket is fitted with a screened bottom and a cam-operated hydraulic vibrator. The vibrating bucket removes a large load from the streambed, then dips in and out of the water. Fine sediments are screened out of the load and settle to the bottom. The coarse spawning material that remains is laid over top of the fines.

Design and Installation Guidelines

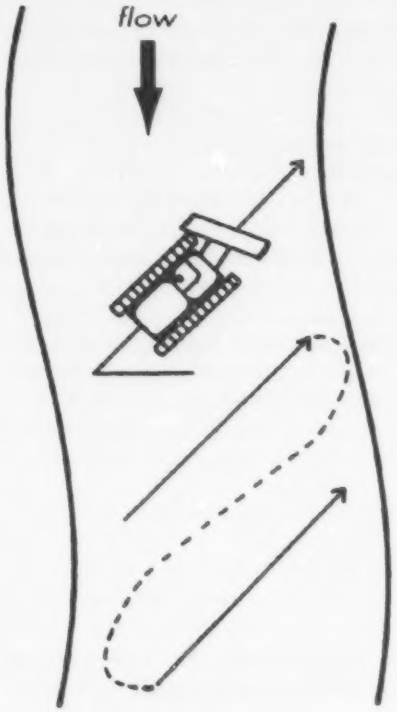

Figure 7.2 Operation pattern for cleaning of gravel with a bulldozer (from Reeves and Roelofs, 1972).

Manual Techniques

On a smaller scale, substrates can be scarified using shovels and rakes to lift up the substrates and expose them to the flow so that fines are separated and washed downstream. Substrates should be cleaned to a depth of at least 30 centimetres.

Hydraulic Flushing

High pressure jets of water and air can be used to clean spawning areas by forcing the substrates, particularly the fines, up into the current of the stream. The fines are transported downstream, leaving high quality gravel behind. Work should commence at the upper end of the spawning area and proceed downstream.

Air-water Jet Cleaners

Various hydraulic devices have been designed to clean spawning gravel. Many of the more elaborate cleaners showed promise, but in the end were abandoned due to mechanical failure. One successful design employed in British Columbia spawning channels consists of a steel frame supported on steel skids (Figure 7.3). The frame supports two rows of parallel, 50 mm diameter pipes mounted vertically at 45 cm centres. Each row of pipes extends 22 cm below the gravel surface. Clean water is drawn from the channel, mixed with air, and pumped through the pipes into the gravel approximately 500 litres per minute. The fine sediments are flushed upwards and washed downstream. The gravel cleaner is pulled by a track-mounted excavator. A variation of this design pumps the slurry of water and fines onto land adjacent to the stream.

Portable Pumps

A portable water pump and hose, designed for fire-fighting, has been widely used and proven successful where small areas of spawning habitat have required cleaning (Figure 7.4).

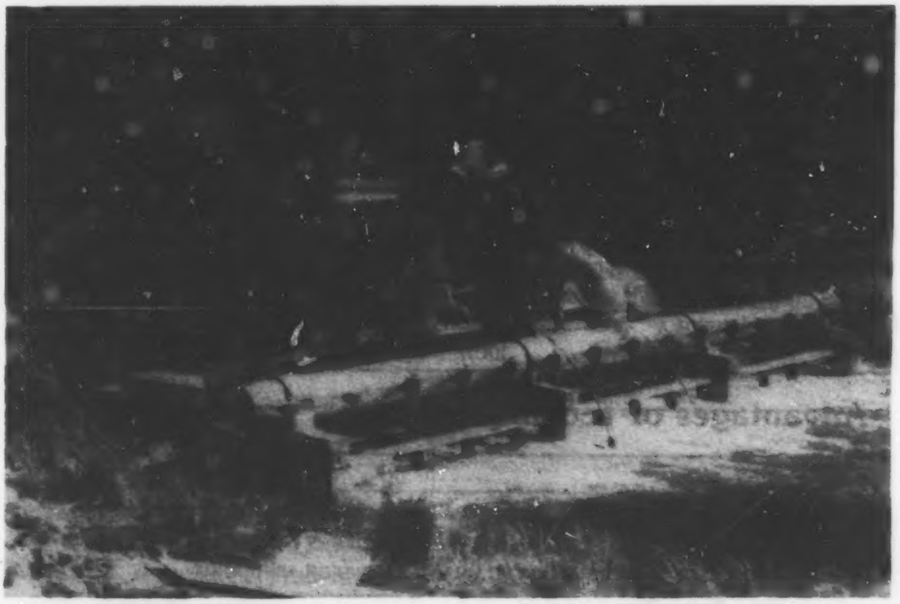

Figure 7.3 Air-water Jet gravel cleaner used at spawning channels.

Figure 7.4 Portable fire pump used to clean gravels.

Maintenance

Since gravel cleaning is itself a maintenance procedure, it may have to be repeated periodically. Many spawning channels were not originally designed to be self-cleaning and therefore require regular cleaning.

Whereas many improvement techniques can be visually inspected to check for maintenance requirements, gravel cleaning projects should be supported by substrate monitoring, since surface substrates do not necessarily represent those throughout the depth of the spawning bed. Sieve analyses are required to evaluate the efficiency of the cleaning technique and assess subsequent changes in sediment composition.

Factors Influencing Cost

- most of the gravel cleaning techniques described require heavy machinery; costs can be high due to the cost of contracting the machinery and operators; other methods tend to be labour intensive
- if heavy machinery is required, availability and site accessibility may affect cost
- substrate consolidation and high concentrations of fines may slow progress or necessitate repeat treatments

Advantages of Technique(s)

- most gravel cleaning techniques are relatively simple
- improvements in gravel quality can be measured immediately after treatment
- the stream retains its aesthetic qualities
- decreased substrate compaction facilitates easier redd construction by spawning salmonids
- production of some aquatic invertebrates may increase following treatment

Disadvantages of Technique(s)

- gravel cleaning tends to destabilize the streambed, making it susceptible to downstream shifting
- fine sediments that are washed away may degrade downstream habitat; rehabilitation of these areas may be necessary
- during the cleaning process, waters downstream will experience an increase in turbidity that may affect resident fish or other water users
- production of some aquatic invertebrates may decline and be slow to recolonize following treatment

Examples of Use

Mechanical Scarification

Big Qualicum River, Vancouver Island, B.C.: A bulldozer is used periodically to improve spawning habitat for chinook, coho and chum salmon, and steelhead trout in the Big Qualicum River. Repeat treatments are necessary due to the high sediment load of the river.

Horsefly River, B.C.: The velocity segregation technique was tested in the Horsefly River in 1973 but was deemed a failure. Gravel permeability and egg-to-fry survivorship did not show improvement despite the fact that large numbers of spawners used the area.

Nadina River, B.C.: The velocity segregation technique produced significant improvements in gravel permeability in the Nadina River, however, spawning fish chose not to use the cleaned areas.

Hydraulic Flushing

Air-water jet cleaners are used in most spawning channels in British Columbia with great success. Attempts to use this type of equipment to clean spawning gravels in the Horsefly and McKinley rivers were not effective as large boulders interfered with its operation.

Ruby Lake, Sechelt, B.C.: A portable fire pump and hose has been used to clean spawning gravels in the outlet stream of Ruby Lake. The cleaned gravels are used by spawning cutthroat trout.

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8 *Artificial Spawning Channels*

Introduction

Spawning channels, are designed to duplicate the most favourable characteristics of natural spawning habitats. The present level of technology permits construction of channels that greatly exceed the production potential of similar sized natural spawning habitats. Spawning channels are not constructed in existing fish bearing habitats. They are usually constructed adjacent to existing streams in order to complement existing habitats. Spawning channels are built primarily for lake and ocean-rearing salmon (sockeye, pink and chum). Since these species have little or no stream rearing requirements, production is not limited by the carrying capacity of the adjacent stream system.

Three factors that can limit salmonid spawning and incubation success. They are spawning area, gravel quality, and water conditions.

Gravels in spawning channels are sorted to the preferred size, shape and distribution for the target species, and are free of fine sediment and debris. Channels are designed so that hydraulic conditions such as depth and velocity are optimal for spawning.

Spawning channels range in size from small, straight channels of under 100 metres to elaborate channels that double back on themselves over lengths of several kilometres (Figure 8.1).

This chapter presents only a brief overview of spawning channels. They are not dealt with in great detail as they require substantial technical expertise and planning, and are relatively costly compared to other stream and small river enhancement projects described in this guide. Most spawning channels are constructed by resource management agencies.

Figure 8.1 The Weaver Creek spawning channel – Fraser Valley.

Application

Before commencing any spawning habitat creation or improvement project, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

Substantial technical input from both biologists and engineers is required to plan, design and construct a spawning channel. This technical expertise exists within resource management agencies. All but the smallest projects should directly involve these agencies.

Artificial spawning channels are created primarily for sockeye, pink or chum salmon, which have little or no stream rearing requirements; however, sockeye juveniles are lake-rearing. Therefore the availability and capacity of nursery lakes in the system should be assessed when planning a sockeye spawning channel.

An adequate source of clean water must be available at or near the project site. The water should be cool, well-oxygenated and free of sediments.

The proposed site for the channel must be large enough to accommodate the channel and all related features such as settling basins, dykes, storage buildings and roadways. The site should be of low relief to minimize the need for surface grading. Flood protection must be provided if the channel is constructed adjacent to a stream or river.

Design and Installation Guidelines

Designers of spawning channels attempt to reproduce all of the best characteristics of natural spawning areas, including a stable flow of cool, clean water of optimal depth and velocity, and gravels of preferred shape and size. General design criteria are provided in Table 8.1.

Control structures regulate the flow in the channel. Settling basins minimize the sediment load of water diverted from streams. Channel dimensions, gradient and drop structures control water depth and velocity. Rounded gravels free of fine sediment are provided as spawning substrate.

Many channels include holding pools and/or overhanging vegetation to provide cover for spawners. Some include facilities to enumerate adults and fry, structures for predator control and areas for public viewing.

Maintenance

Spawning channels that use diverted stream water will require periodic cleaning to remove fines (refer to Chapter 7). Settling basins will also require regular cleaning. Occasional replacement of gravels may be required in some channels. Periodic addition of rip rap may be required to stabilize channel banks and dykes. Flow control, diversion and drop structures will also require general maintenance.

Design and Installation Guidelines

***Table 8.1** General design criteria for sockeye, chum and pink salmon spawning channels in British Columbia.*

Width (metre)	*6.1 - 25.0*
Channel Slope (%)	*0.05 - 0.20*
Side Slope (x:1)	*1.2 - 2.1*
Depth (m)	*0.24 - 0.48*
Velocity (m/s)	*0.27 - 0.58*
Flow (m^3/s)	*0.41 - 3.63*
Flow (m^3/s *per m of width)*	*0.07 - 0.24*
Gravel Size (mm)	
- chum	*19 - 152*
-sockeye/pink	*13 - 102*

Factors Influencing Cost

- cost of land acquisition and site preparation
- project location and accessibility
- source of water and conveyance distance
- number and size of features such as settling ponds, stream diversions, drop structures and barrier dams
- availability of materials

Advantages of Technique(s)

- benefit-cost ratios of 2:1 and higher are not uncommon for large channels with good design features. Spawning channels are among the most economical improvement options
- spawning channels can significantly increase natural production
- substrates, hydraulic conditions and water quality can be controlled to create optimum spawning conditions
- when protected by dykes, channels are not susceptible to damage by floods
- spawning channels may provide incidental rearing habitat; for example, coho juveniles may utilize rip rap banks for cover
- enumeration facilities can be incorporated into the channel design so that production can be measured directly

Disadvantages of Technique(s)

- a high level of technical expertise is required to plan, design, and construct a spawning channel
- high cost: heavy machinery and material costs
- water storage may be required if uncertain flow conditions prevail at any time of the year

Examples of Use

Fraser River System, B.C.: The International Pacific Salmon Fisheries Commission constructed spawning channels for sockeye and pink salmon at Weaver Creek, Nadina River, Pitt River, Gates Creek and Upper and Lower Seton Creek. To 1978, average egg-to-fry survivorship was in the range of 50-80%. Flood damage at the Weaver Creek channel in 1977 reduced the egg-to-fry survival to 25% from the average of 74% achieved over the twelve previous years.

Big Qualicum River, B.C.: Two spawning channels were constructed at the Big Qualicum River in 1963 and 1967. Spawning channel No. 1 suffered severe silting problems that were attributed to insufficient channel gradient (0.09%) and lack of a settling basin. High egg retentions and low egg-to-fry survivorship (mean of 32.9%) led to the conversion of this channel to a rearing channel in 1967. Spawning channel No. 2, built in 1967, was designed with a settling basin, steeper gradient (0.20%) and pools at the top end of each of 19 sections. Egg-to-fry survival from 1967 through 1972 was 74.5%.

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9 *Artificial Incubators*

Introduction

Incubating salmonid eggs require a continuous flow of water to provide adequate levels of dissolved oxygen and remove metabolic wastes. An intragravel flow rate of 100 cm per hour generally produces high egg-to-fry survivorship. A large percentage of fine sediments in natural incubation substrates decreases permeability and intragravel flow rates to levels insufficient for proper egg development and high egg-to-fry survivorship.

In much the same way that an artificial spawning channel provides salmonids with ideal conditions for spawning, artificial incubators provide salmonid eggs with optimal conditions for development.

Incubators provide a continuous supply of water by eliminating or reducing fine sediments from the incubating medium. Fertilized salmonid eggs are placed in incubators at densities that eliminate egg loss due to disease and predation.

This chapter addresses three types of artificial incubation: 1) incubation boxes; 2) instream incubators; and, 3) lake incubators. An incubation box is essentially a gravel-filled box located adjacent to a stream. Gravity-fed water is piped to the bottom of the box. It upwells through the gravel to the top of the box and overflows back into a trough which returns the water to the stream channel. Instream incubators are installed either on or under the streambed surface taking advantage of natural surface or intragravel flow. Instream incubators may or may not be gravel filled. Lake incubators are basically screened trays or compartments that are suspended in the water column where currents provide adequate flow. Gravel is not used in lake incubators. Instream and lake incubation techniques have had limited use and should be considered experimental.

Application

Before commencing any salmonid egg incubation project, contact the Department of Fisheries and Oceans community advisor for your area. The advisor will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

Artificial incubation may be employed where salmonid production is limited by the amount and quality of spawning habitat. If the objective is to produce stream-rearing species, there must be sufficient rearing habitat available. Incubators may be used where spawner numbers are too low to adequately seed available habitat, or as a temporary measure to colonize inaccessible or rehabilitated stream sections.

Streamside incubators can be used on streams with extreme flows, high sediment loads and unstable substrates. Intake screens and settling boxes are required for streams with high sediment loads. Moderate to high gradient streams are generally required to provide adequate flows. On lower gradient streams, long intake pipes or a small dam may be required.

Numerous designs and techniques have been applied to instream and lake incubation. All are considered experimental and, until methods are refined, should be applied only by, or under the supervision of, resource agency personnel. Instream incubators are used in streams with stable substrates and low to moderate sediment loads. Lake incubators are best used in lakes where there is little or no wave action, particularly if **green eggs** are used.

Design and Installation Guidelines

All artificial incubators require fertilized salmonid eggs. These can be obtained by artificially spawning mature adults that have been captured and held until ready to spawn. Eggs should be left to water-harden for about one hour and placed in the incubator within 24 hours. After the first 24 hours, the fertilized eggs become shock-sensitive and remain so until they reach the eyed stage (two to three weeks). Most egg mortalities occur during this shock-sensitive period. If fish culture facilities are available, the eggs can be allowed to develop to increase survivorship.

Incubation Boxes

There are many designs for streamside incubation boxes, but most are variations of a basic design in which clean gravel and a continuous upwelling of clean, cool, aerated water are provided for the eggs. Some incubation boxes can accommodate over 50,000 fertilized salmonid eggs and achieve egg-to-fry survival rates of 80 to 100 percent. Eggs and gravel can either be layered in an incubation box, or the eggs can be placed in a tray suspended above the gravel. The latter approach allows for inspection and removal of dead eggs. A typical incubation box and associated features is shown in Figure 9.1.

Incubation Box

Plywood is the most common material for box construction. It should be painted with a non-toxic paint or coated with fiberglass. Brass, copper and galvanized metals should not be used in any components of the incubator as they are toxic to fish. In regions that experience cold winters, the box should be insulated with Styrofoam™. A grate should be set about 5 to 10 centimetres from the bottom of the box so that water introduced at the bottom is evenly distributed for upward flow. A 2 mm mesh over the grate will prevent alevins from swimming down. Fertilized eggs are placed in the box between layers of gravel or on screens above the gravel. Gravel depth should not exceed 0.6 metres. The box may be fitted with optional windows on either the side or the top for observation, but should be covered to prevent extended light exposure which can harm the eggs. The box can be divided into compartments to control the spread of disease. The box should be located where it will not be susceptible to damage by high flows.

Live Box

Fry that emerge from the gravel can be held in a live box for enumeration. The live box can be constructed as part of the incubation box or as a separate unit. A pipe or flume can be used to carry the fry to the live box, or directly to the stream.

Water Intake and Settling Box

The intake should be screened to eliminate debris, coarse sediment and predators from the water supply. The intake should be located at the bottom of a pool and anchored in place. For streams with high sediment loads, a settling box should also be installed to intercept fine sediments. The settling box should be located above the high water level and installed at a higher elevation than the incubation box to maintain gravity flow through the system.

Gravel

For most salmonids, a mix of gravel 19 to 38 mm is suitable. Large gravel is preferable to small gravel, as the larger material permits better flow and easier movement of fry. Synthetic materials such as plastic bio-rings can be used in place of gravel.

Design and Installation Guidelines

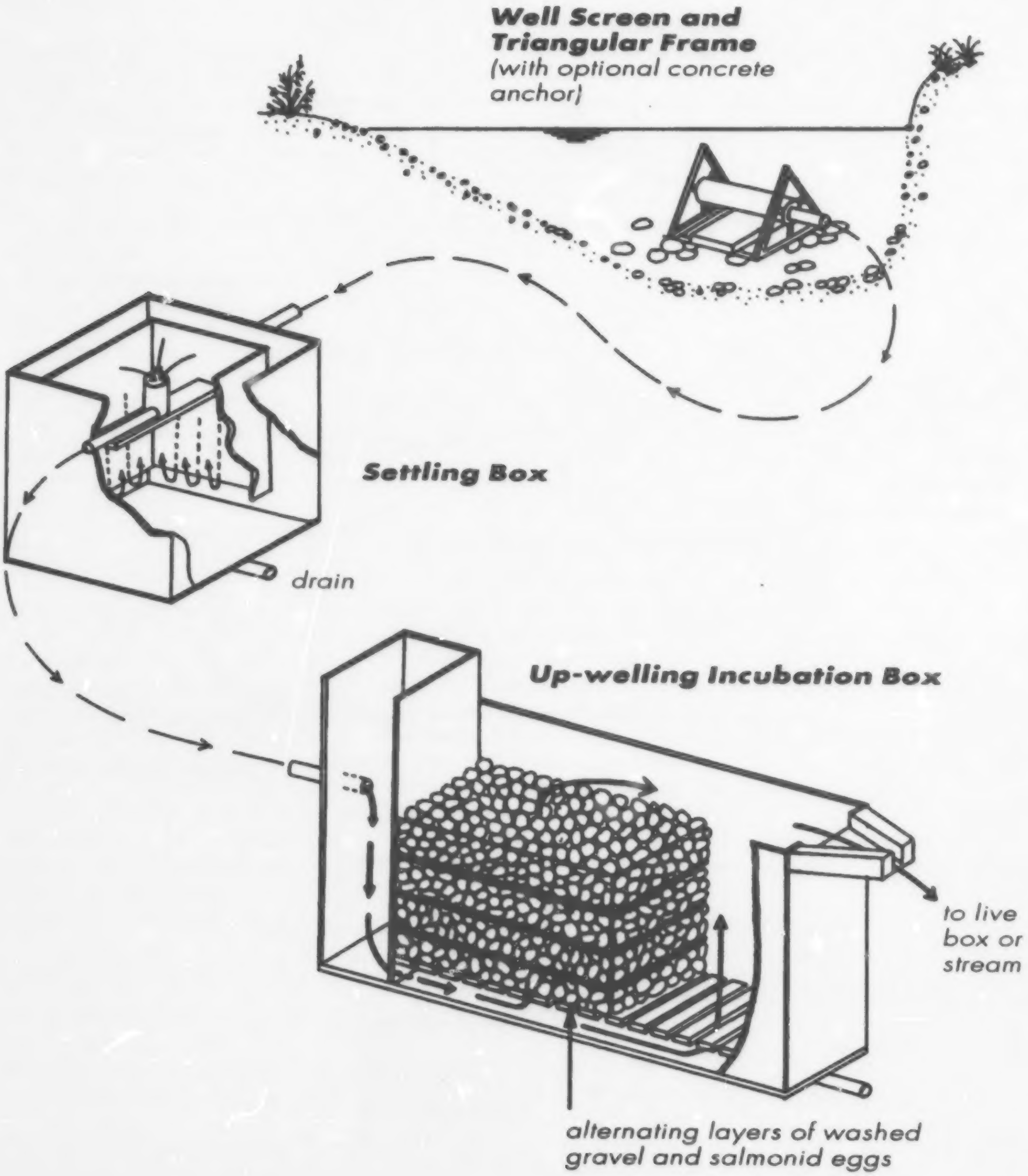
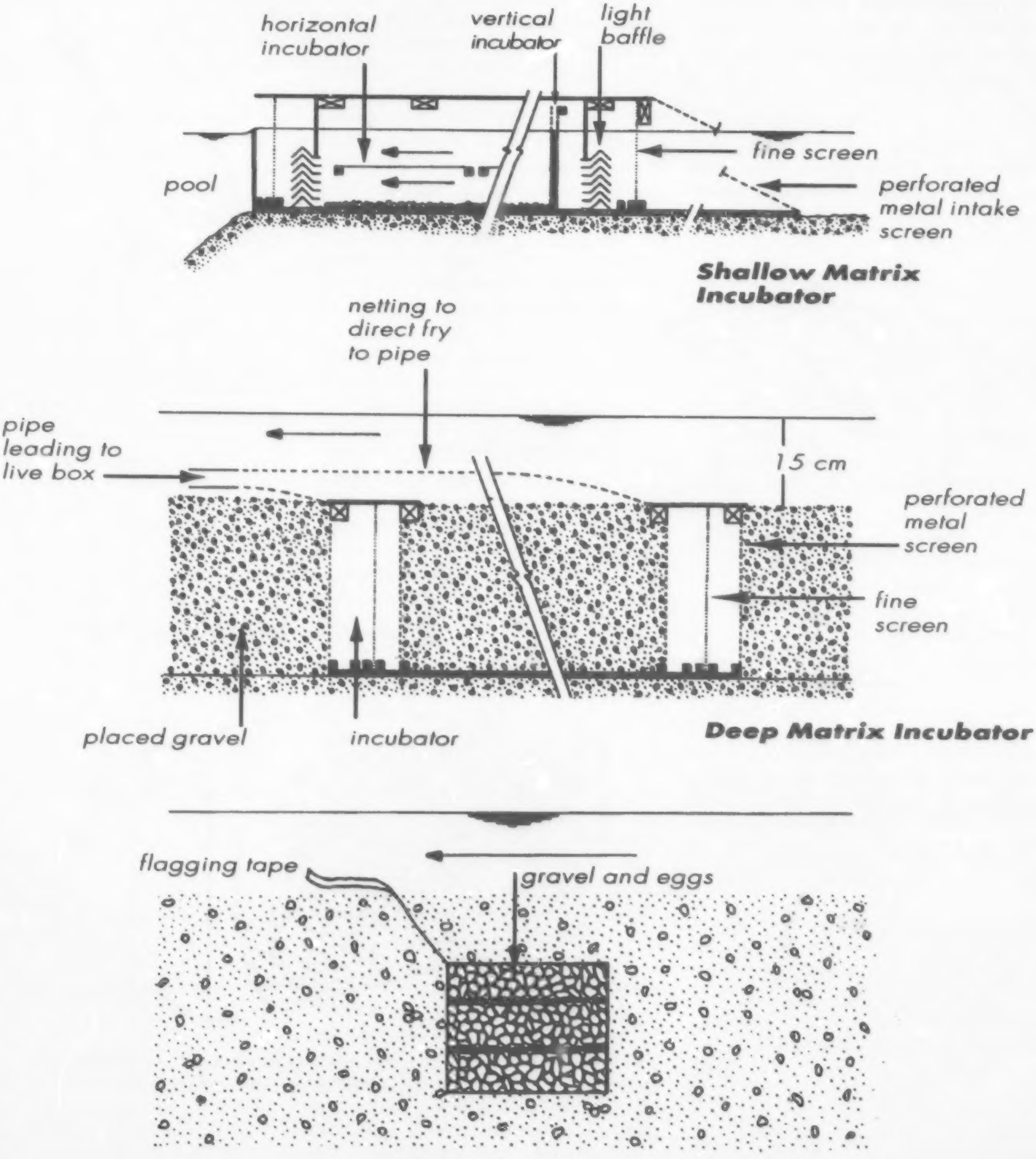

Well Screen and Triangular Frame
(with optional concrete anchor)
Settling Box
drain
Up-welling Incubation Box
to live box or stream
alternating layers of washed gravel and salmonid eggs

Figure 9.1 A streamside incubation box and related features.

Design and Installation Guidelines


horizontal incubator
vertical incubator
light baffle
fine screen
pool
perforated metal intake screen
netting to direct fry to pipe
pipe leading to live box
15 cm
perforated metal screen
fine screen
placed gravel
incubator
flagging tape
gravel and eggs

Shallow Matrix Incubator

Deep Matrix Incubator

Basket Incubator

Figure 9.2 Several types of instream incubators.

Design and Installation Guidelines

Water Supply

There are many factors to consider when selecting a water source. A qualified biologist or hydrologist should be consulted for this task. A regulated flow of cool, aerated, silt-free water is required. For every 1,000 eggs placed in the incubator, a flow of about 1 litre per minute is required. Valves should be installed in the system to control the flow rate. Pipes for water delivery should be made of polyethylene, as most metals are toxic to fish. A minimum head of water of 0.5 metres should be maintained between the intake and the settling box, and another 0.5 metres between the settling box and the incubation box. The greater the head of water, the greater the potential flow rate through the system. Lower gradient streams will require either longer pipes to the intake or a small dam to create the necessary head.

Instream Incubators

Instream incubators are containers that house developing salmonid eggs and are permeable to the natural flow of water in a stream. Various types of instream incubators have been developed and employed successfully (Figure 9.2), however, most are presently considered experimental. Instream incubators may be designed for use both on or below the streambed surface, and have been built to accommodate up to 40,000 eggs.

The most favorable results seem to be associated with small incubator designs. One such design employs flat-bottomed baskets 15 cm in diameter by 10 cm in height. The basket walls are made of screened material (2 mm openings). The basket is filled with clean gravel and 200 to 300 fertilized eggs. The top is left open to allow fry to escape. The baskets are placed in holes excavated in the streambed then carefully backfilled. Coloured streamers attached to the baskets allow them to be relocated later for inspection.

The Whitlock-Vibert box (Figure 9.3) is a variation of this concept. It is a slotted plastic box measuring 15 x 9 x 6 cm. The 11.5 x 3.3 mm slots retain the eggs but allow emerging fry to escape.

Another instream incubation design and technique that has shown promise uses small, interlocking chambers buried in the streambed. Fungus and disease are prevented from spreading from one chamber to another preventing high mortality.

Lake Incubators

High egg-to-fry survivorship has been achieved with lake incubators in experimental studies conducted throughout the Pacific Northwest. Fertilized eggs are placed on horizontal trays or in vertical cassettes (Figure 9.4) that are submerged at depths of one to two metres at a location where there is a slight current. The incubators can either be placed on the lake bottom or suspended from a floating platform. The site chosen for installation must have a sufficient current to oxygenate the eggs but should not be subject to wave induced turbulence. Algae may accumulate on incubator screens and prohibit the exchange of water. Removal of this algae is necessary to prevent egg loss.

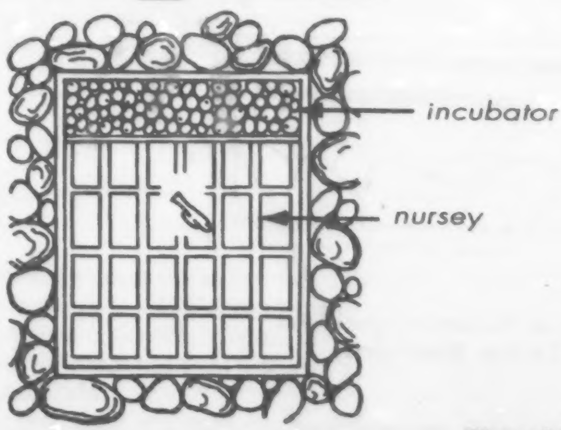


Figure 9.3 The Witlock-Vibert box.

Design and Installation Guidelines

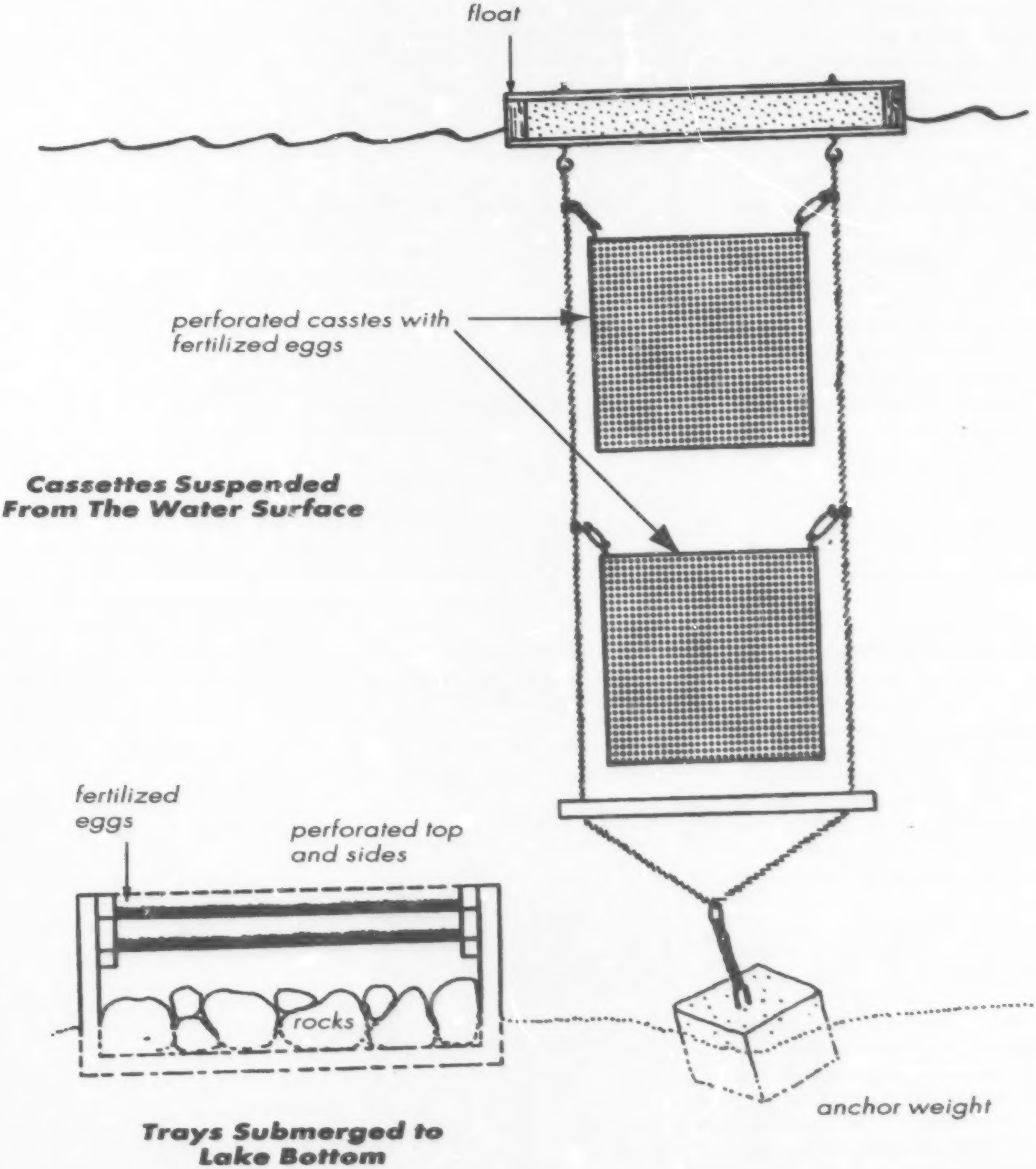

float
perforated casstes with fertilized eggs
Cassettes Suspended From The Water Surface
fertilized eggs
perforated top and sides
rocks
anchor weight
Trays Submerged to Lake Bottom

Figure 9.4 Experimental designs for lake incubators.

Maintenance

Incubation Boxes

Streamside incubators must be checked regularly to ensure that an adequate flow of clean water is maintained, particularly after periods of high flow or freezing weather. Intakes and settling boxes should be cleaned. Flow rates should be monitored and adjusted. Eggs placed in trays at the top of the incubation box should be regularly inspected and dead eggs removed. Fungus may be controlled by regular treatments with a fungicide.

Most instream incubators are buried in the streambed and are left there until after the fry have emerged. No maintenance is required.

If practical, lake incubators should be inspected regularly. Dead eggs should be removed and algae should be cleaned from screens.

Factors Influencing Cost

Incubation Boxes

- construction and operation of incubation boxes are labour intensive
- egg capacity of the box and required options (settling box, live box, windows, well screen) will affect the amount and type of materials required
- low gradient streams may necessitate the construction of a small dam or use of long conveyance pipes to create the head of water required

Instream Incubators

- small, basket-type incubators can either be purchased from suppliers or be constructed with commonly available materials. The latter may provide a cost saving but is more labour intensive
- basket-type incubators have a relatively low egg capacity, therefore, many incubators are required to produce large numbers of fry
- larger instream incubators (shallow-matrix and deep-matrix) are labour intensive to construct, install and monitor

Lake Incubators

- incubators with high egg capacities can be constructed and installed at relatively low costs
- eyed eggs may be preferable for some incubators (e.g.. those with surface floats); eggs must be developed for several weeks at a fish culture facility

Advantages of Technique(s)

- egg-to-fry survival rates for most artificial incubators are significantly higher than for naturally spawned and incubated eggs
- incubators are a relatively inexpensive technique for increasing salmonid fry production.
- artificial incubators can be used temporarily to establish populations upstream of barriers or where degraded habitat has been recently rehabilitated
- fry production and egg-to-fry survival rates can be accurately measured

Disadvantages of Technique(s)

- fertilized salmonid eggs are required; adults must be collected and artificially spawned, then eggs must be carefully handled; if eyed eggs are required, fish culture facilities must be available
- incubation boxes require constant maintenance; water flow can be a serious problem during freezing weather; ice may develop and eliminate flow; annual labour requirements can be high
- eggs in lake incubators may be susceptible to shock from wave action or loss of flow due to accumulation of algae on screens

Examples of Use

Incubation Boxes

There are well in excess of 100 incubation boxes operating throughout British Columbia. Most are used to produce chum or coho salmon. Streams with incubation boxes in southwestern British Columbia include the Coquitlam River, Hastings Creek, Hyde Creek, Nicomekl River, McKay Creek, Maplewood Creek and Stoney Creek. In interior regions of the province, incubation boxes are in operation on the Barriere River, Chilako River, Duteau Creek, Fennel Creek, Fortune Creek and Yalakom River.

Instream Incubators

Big Qualicum River, Vancouver Island, B.C.: Shallow-matrix, deep-matrix and basket incubators were assessed in two successive years in a diversion channel of the Big Qualicum River. Basket incubators were found to be most effective, yielding a mean survival rate of 68% in the second year. Deep-matrix incubators were intermediate in effectiveness; shallow-matrix incubators were the least effective.

Lake Incubators

Lake incubators of various design have been evaluated at sites throughout the province, including Keogh Lake, Vedder River Bridging Pond, Skidegate Lake, Barriere Lake and Upper Babine River. Physical shock resulting from wave action caused high rates of mortality in green eggs at the Keogh Lake site. Accumulations of algae were responsible for poor survivals at Skidegate Lake and Barriere Lake. Survivorship at the Vedder River Bridging Pond and Upper Babine River were high (90 - 95%).

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10 *Mainstem Rearing Habitat*

Introduction

One of the most critical components of salmonid habitat is cover, particularly for rearing juveniles. Rearing fish tend to occupy covered habitats for extended periods of time. They rarely leave these areas except for short foraging and feeding excursions into more exposed stream habitats. Cover requirements vary between species and size of fish, and between time of day and season. Salmonid streams, especially those supporting more than one species, should contain a diversity of cover types. Submerged cover such as large organic debris, boulders, rubble and aquatic vegetation afford protection from predators, while overhead cover such as floating debris, undercut banks, turbulence and overhanging vegetation provide shade as well as protection from predators.

Pools are also an essential element of salmonid habitat. They provide refuge for salmonids during periods of flood, drought and ice formation.

A wide variety of techniques are available for either increasing the amount of cover or a number of pools in a stream. Many rearing habitat improvement techniques produce other benefits that may include collection of spawning gravels, removal of fine sediments, and increasing the food supply by providing substrates that enhance the production of aquatic invertebrates that are important fish food items.

This chapter presents a variety of techniques for creating mainstem rearing habitat. General categories include: full-spanning structures; partial-spanning structures; large organic debris; log cover and blast pools.

Application

Before commencing any mainstem rearing habitat creation project, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

Streams possessing little or no instream cover and shallow pools can be improved through the addition of instream structures. Stream gradients should range between 0.5 and 3.0%. Structures must be designed to function during low flows and be stable during high flows. Instream structures should be installed where streambanks are low and the channel width is greater than the mean channel width. Water velocities and hydraulic forces are reduced in wider stream sections, thus minimizing the potential for structural failure.

Design and Installation Guidelines

Instream structures are subjected to tremendous forces during high flows. These forces may contribute to structure failure. Instream structures are also capable of altering flow and channel patterns, potentially impacting productive fish habitat downstream and/or upstream of the structure and adjacent upland environments. An experienced hydrologist or hydraulic engineer should be consulted for advice regarding design and placement of instream structures.

Design and Installation Guidelines

Instream structures must be secured to the streambed or to large immobile objects. The recommended approach for securing or anchoring logs or rock to the streambed is to drive reinforcing rod (rebar) through pre-drilled holes into the streambed. Instream materials can be secured to objects on the streambank using chain or aircraft cable. When anchoring to live trees, a wide collar of metal flashing or large diameter hose should be used to prevent the chain or cable from harming them. Rock bolts with eyes may be used to fasten cables to large boulders or, alternatively, resins may be used to fasten cable directly to boulders. Both rock bolts and resin fasteners require predrilled holes in the rock.

Instream work should be undertaken during the late summer, low flow period when utilization of the stream by salmonids is at its lowest level.

Full-Spanning Structures

Full-spanning structures extend across a stream channel and are keyed into the banks on both sides. They are generally used to create pool cover. Plunge pools may form under and immediately downstream of structures as a result of water falling over the structure. Scour pools develop downstream of the structures as a result of redirected and concentrated flow.

In all natural streams with substrates coarser than sand, the streambed alternates along its length between riffles and pools. Depending on the amount and size of instream structure, pool-and-riffle sequences usually repeat at intervals of every 5 to 7 channel widths. This natural sequence should be maintained when installing instream structures, otherwise the stream will react to regain it. Structures can be installed to complement the natural stream form. Two types of full spanning structures are discussed: weirs and Hewlitt ramps.

Weirs

Weirs built perpendicular to the direction of flow are the most basic full-spanning structures. Constructed with either large rocks or logs, these structures cause water to scour plunge pools along their downstream edges. The proximity of the plunge pool to the weir can be altered by sloping the front face of the weir (Figure 10.1). Water flowing over a sloped weir erodes a pool further away from the weir and may prevent undermining of the structure. Weirs should be installed at least 0.3 metres below the streambed and should be well armoured at both banks to prevent erosion during high flows.

Increased stability has been achieved by installing full-spanning structures diagonally across stream channels. The energy of flowing water is spread out over a greater length and reduces the incidence of structural failure. Diagonal weirs may be used to redirect the flow of water towards a bank to accelerate scour or, conversely, away from a bank to protect it from erosion. Three designs, a diagonal weir and two variations, the "V" and "Y" designs, are recommended. Diagonal weirs should be installed 20-45 degrees from the streambank. The diagonal components of the "V" and "Y" designs should also be constructed at these angles. The "V" and "Y" designs are slightly more complex to build but create more diverse habitat. Scour and depositional patterns associated with these three designs are shown in Figure 10.2.

Hewlitt Ramps

A Hewlitt ramp is a type of full-spanning structure suited to small streams with stable flows. It is an inclined surface installed across the width of a stream to form a self-scouring pool (Figure 10.3). Water drops over the downstream end of the ramp, creating a plunge pool which extends back under the ramp. The pool provides cover for rearing fish and affords easy passage to upstream migrants.

Design and Installation Guidelines

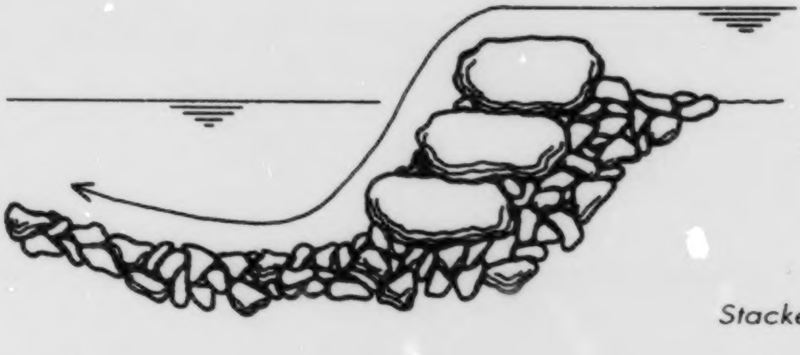
Hewlitt ramps are typically constructed with wood (logs and boards). Cedar is recommended as it tends to resist rotting better than other woods. The log that forms the weir must be anchored into each bank and armoured with rip rap to prevent erosion of the banks during high flows. Hewlitt ramps may also be constructed using large, flat rocks.

Partial-Spanning Structures

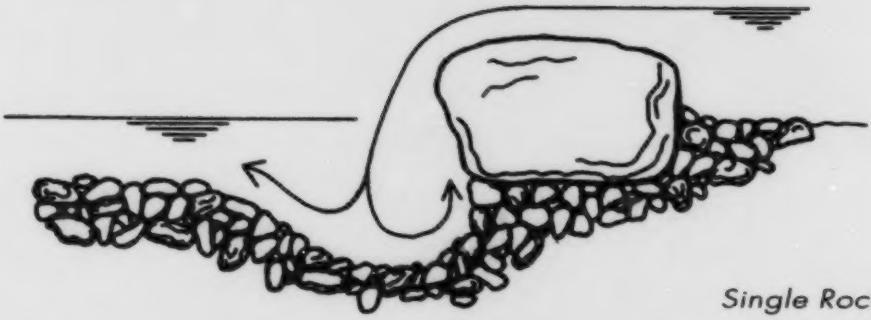
Structures that extend only part of the way across a stream channel can be used to create scour pools either along the banks or mid-channel. Two primary types of partial spanning structures are deflectors and boulder groups.

Deflectors

Flow deflectors are designed to redirect the flow of water to scour bed material. Installed along the upstream edge of a channel bar, a deflector can increase scour at the opposite side of the stream. Displaced material will be deposited below deflectors further downstream. A series of deflectors can be installed along a stream to enhance the natural meander pattern of the stream.



Stacked Rock Weir



Single Rock Weir

Figure 10.1 Pool development below rock weirs.

Design and Installation Guidelines

The recommended material for construction of deflectors in coastal streams is rock. The size of rock required is a function of peak flow conditions and stream gradient. In general, rock should be at least 60 centimetres in diameter for the upstream face of the deflector. Deflectors may be attached to a streambank or constructed in the middle of the channel. The most stable deflector is the triangular wing design. Mid-channel deflectors are less stable; however, they do tend to accumulate floating organic debris which provides additional cover for juvenile salmonids.

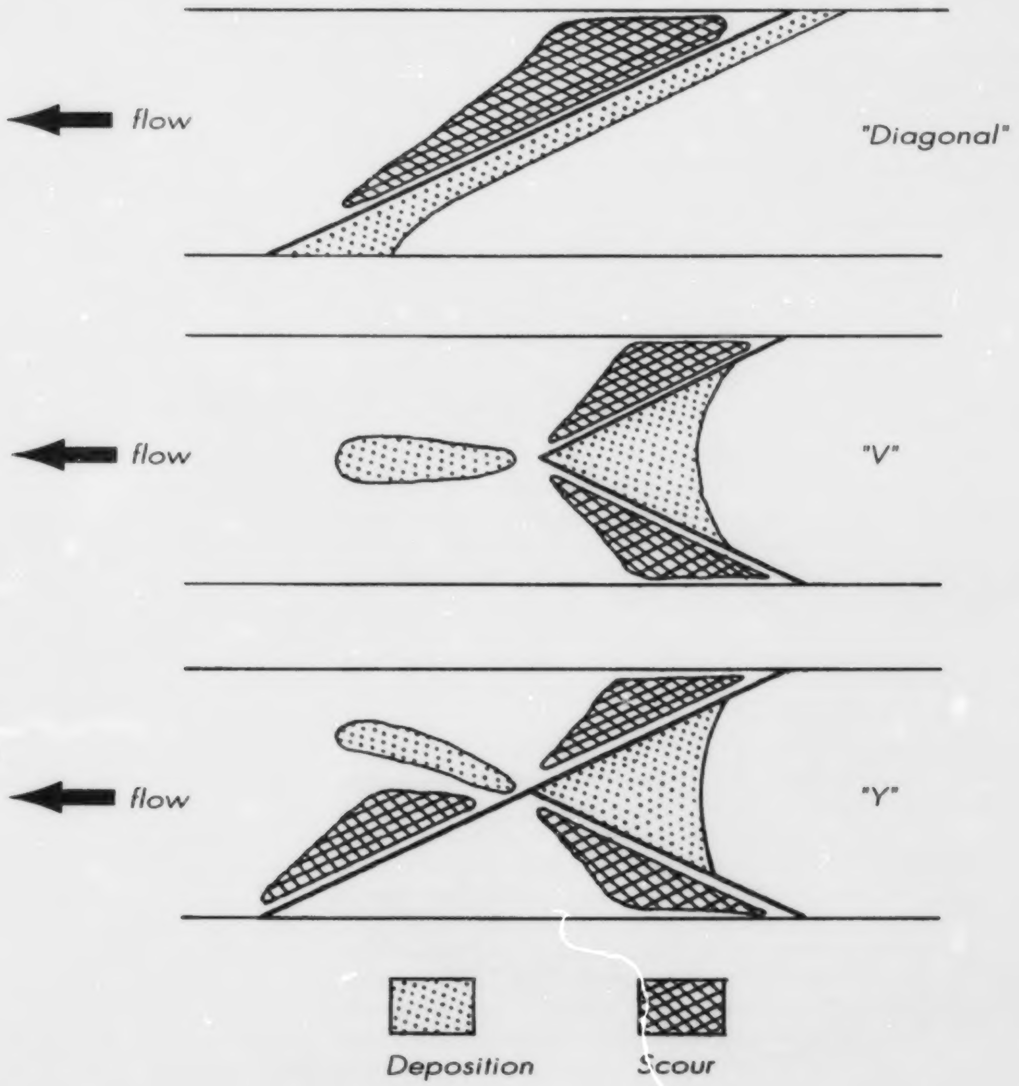


Figure 10.2 Scour and deposition associated with full spanning weirs.

Design and Installation Guidelines

The upstream face of a triangular wing deflectors (Figure 10.4) should form an angle with the streambank of no more than 45 degrees. The angle between the upstream and downstream faces of the deflector should be at least 90 degrees. The deflector should not extend more than 1/3 of the distance across the channel.

A deflector installed along a streambank should be keyed into that bank. The streambank must be protected with rip rap to a point above the high water level to prevent water from washing around the deflector. The streambank opposite the deflector should be armoured with rock to minimize the potential for erosion resulting from the redirected flow. The deflector should be submerged at the point furthest from the bank, sloping upwards towards the bank. The height of the wing deflector should be set so that at peak flows it adequately passes debris. A deflector set too high may result in substantial channel and bank erosion.

Boulder Groups

Large rocks can provide three types of cover for rearing fish: 1) a turbulent surface layer; 2) scour pools; and 3) cover providing overhang. Slack water downstream of large boulders also provides resting areas during high flows. Instream cover can be enhanced by placing several

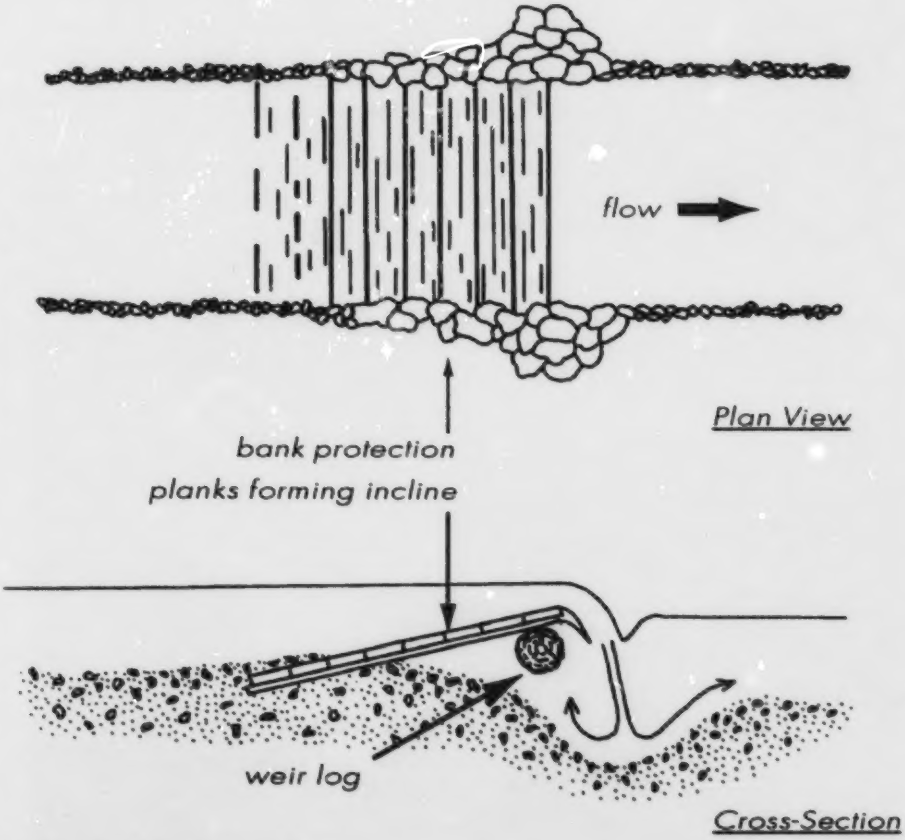


Figure 10.3 Hewlitt ramp design.

Design and Installation Guidelines

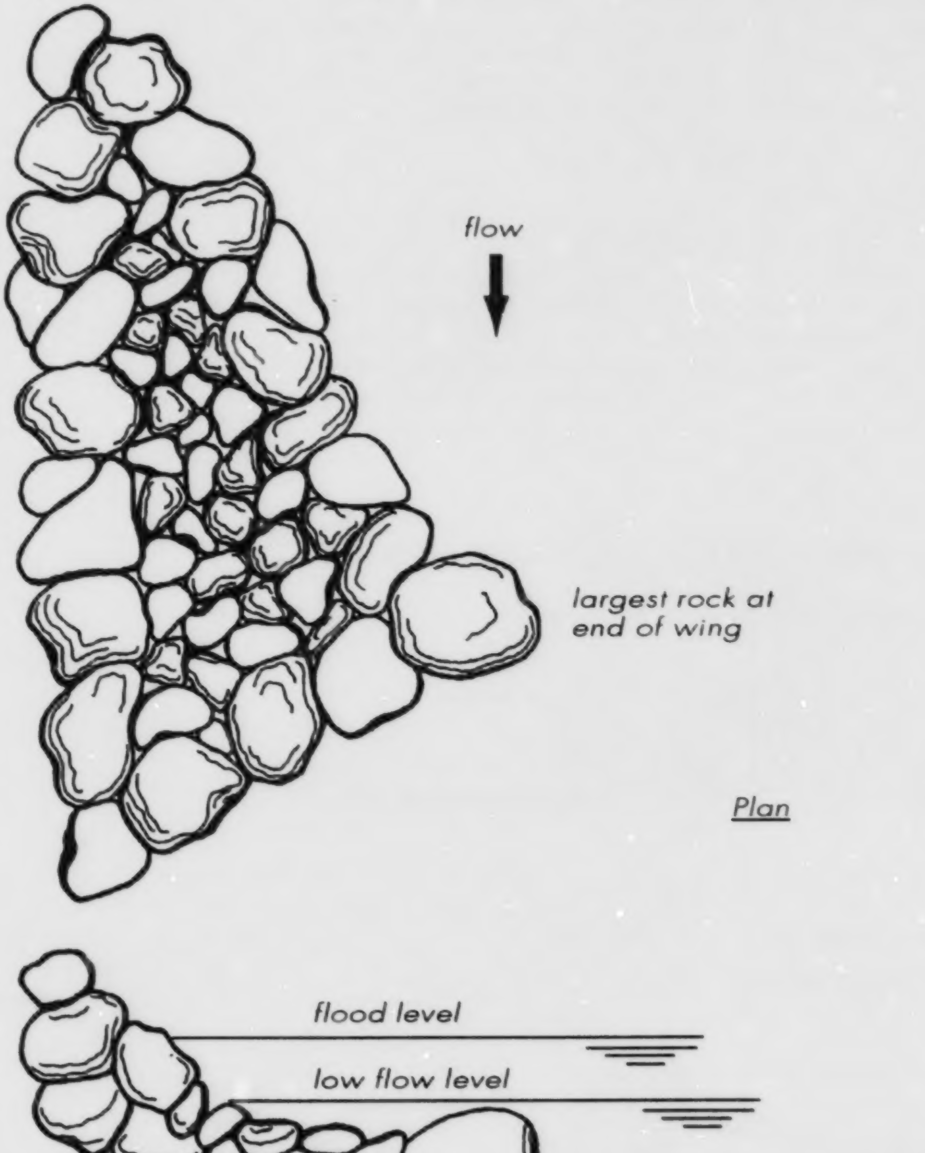

flow
largest rock at end of wing
Plan
flood level
low flow level
Cross-Section

***Figure 10.4** Triangular wing deflector - design considerations.*

Design and Installation Guidelines

boulders in triangular or diamond-shaped configurations. Organic debris that accumulates on the boulder group adds to total stream cover (Figure 10.5).

Boulder groups should be located at the middle or downstream end of a riffle or at the upstream end of a pool or run. In order to ensure that the boulder group remains within the wetted stream area during low flows, they should be installed in the middle third of the channel, in or near the **thalweg**. A combination of boulder groups downstream of paired deflectors provides diverse and year-round habitat (Figure 10.6).

Large Organic Debris

Root wads, trash bundles and trees can be secured at key locations within a stream to increase the amount of submerged and overhead cover for rearing fish. Cedar is the preferred species, but other coniferous species are acceptable due to their high resin content. Fast rotting species such as alder or cottonwood should be avoided.

Sources of material include live and dead trees in the immediate vicinity of the enhancement project, or debris from off-site sources such as urban development and road construction projects. Live trees should not be removed without permission from the B.C. Forest Service or the private landowner.

Large organic debris should be located in either pools or runs along the outside of stream curves. Trees and root wads should be anchored in a manner that avoids damming the flow. Trees should have the branches trailing downstream with the butt section anchored to the streambank. Figure 10.7 shows several techniques for placing and securing large organic debris in streams.

Log Cover

Cedar logs can also be used in various configurations to create rearing habitat. All log structures must be securely anchored. Three common log structures used to create rearing habitat are: floating log rafts; submerged half logs; and log bank cover (Figure 10.8).

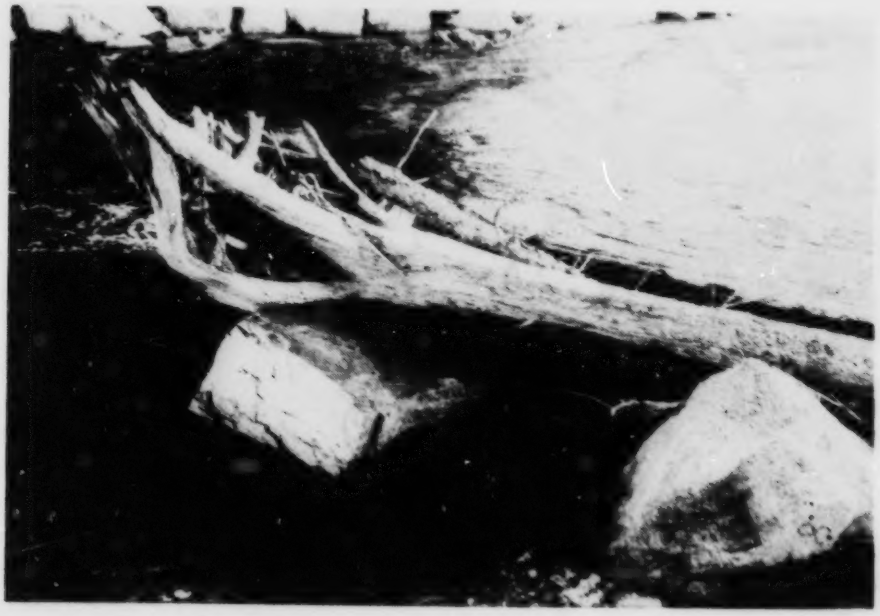


Figure 10.5 Log accumulation on a boulder group.

Design and Installation Guidelines

Several logs can be lashed together to form a raft that can be anchored to either mid-channel structures (e.g. large boulders) or streambank objects (e.g. live trees). Floating rafts should be located in pools or runs of sufficient depth to provide at least 10 cm between the streambed and the bottom of the raft during low flow conditions. When installing floating log structures along streambanks, select steep banks so that the logs do not become hung up on the bank after high flows recede.

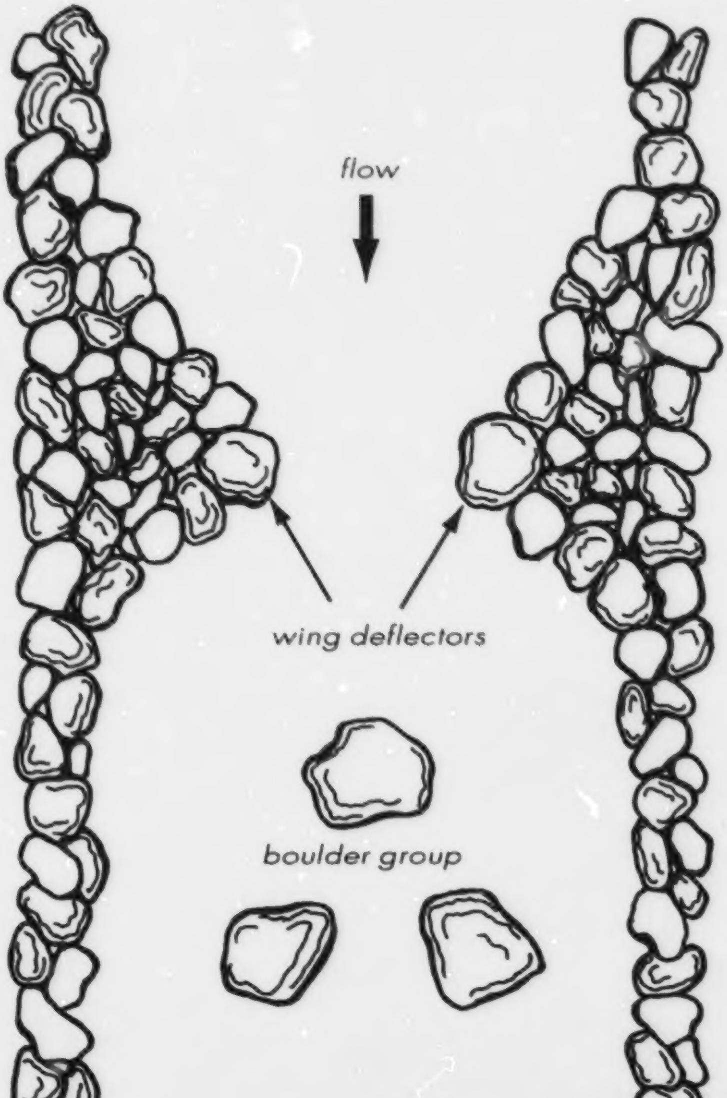
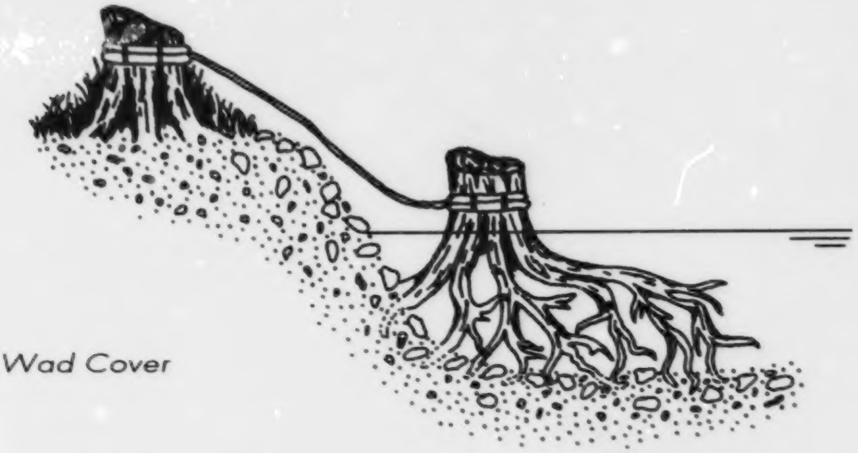


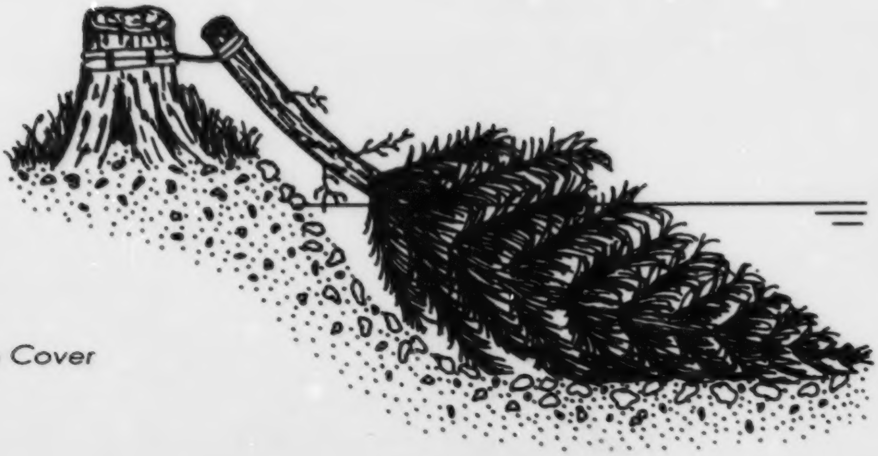
Figure 10.6 Paired deflectors and a boulder group can be used together to provide diverse salmonid habitat.

Design and Installation Guidelines

The submerged half log structure is useful for creating cover in streams with stable flow regimes and low sediment loads. A log is cut in half lengthwise and spacers about 10 cm wide are attached at each end of the half-log on the flat surface. Holes are pre-drilled through the half-log and spacers. The unit is then submerged and fastened to the streambed with reinforcing rods (rebar). The rebar is driven through the pre-drilled holes into the streambed to a depth of approximately



Root Wad Cover



Tree Cover

Figure 10.7 Large organic material such as root wads and trees make ideal cover for rearing salmonids.

Design and Installation Guidelines

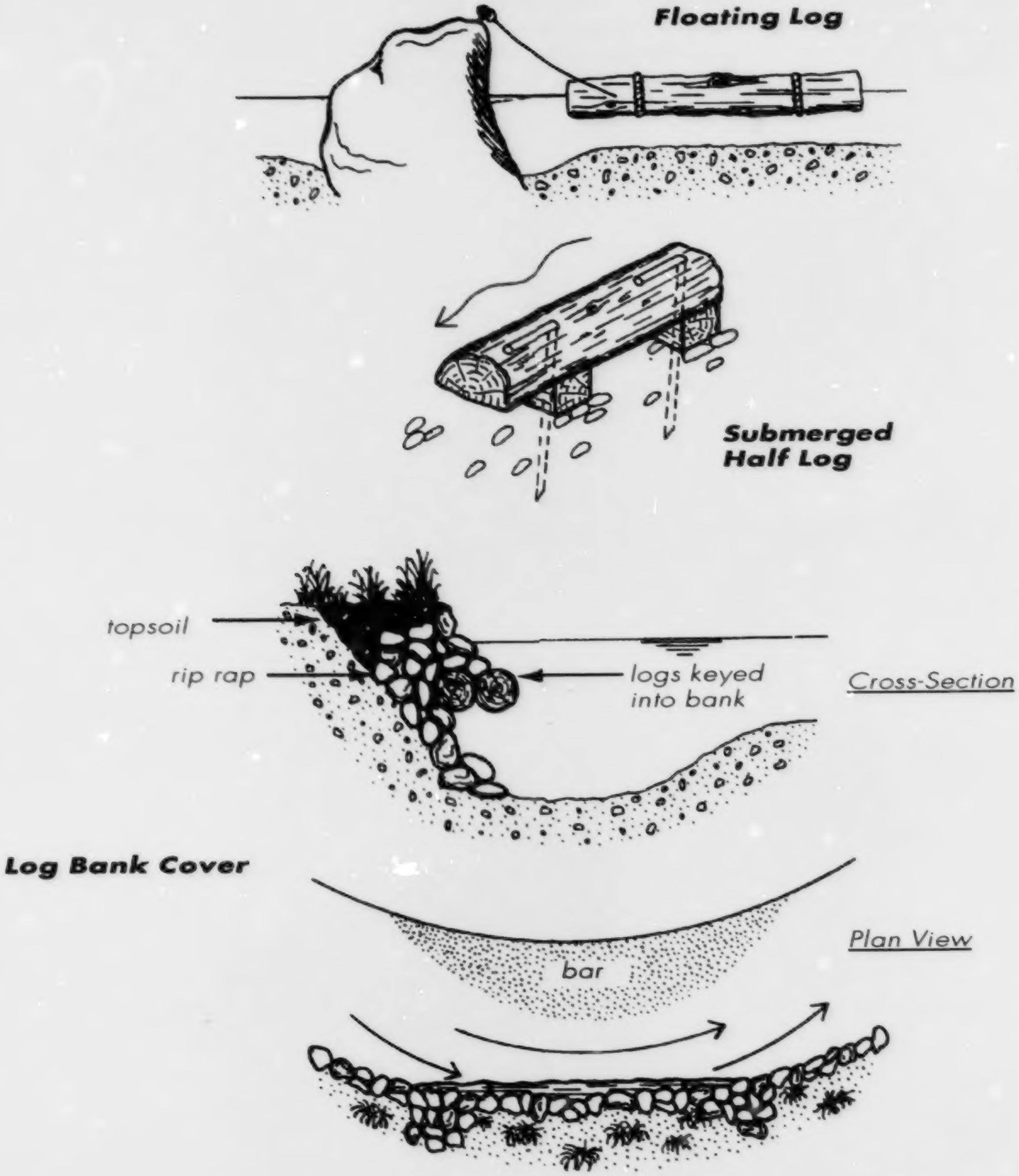

Floating Log
Submerged Half Log
topsoil
rip rap
logs keyed into bank
Cross-Section
Log Bank Cover
Plan View
bar

Figure 10.8 Typical log structures.

Design and Installation Guidelines

1.5 meters. The rebar should be angled (the bottom of the rebar should be further downstream than the top) to increase the stability of the unit. Approximately 30 centimetres of rebar should remain above the half log and be bent over in the downstream direction to anchor the structure.

Sharp curves in small streams are ideal locations for installation of log bank cover. This structure is essentially a series of parallel logs that are bound together and anchored into the bank at two points along a stream curve to form an artificial cutbank (Figure 10.8; 10.9). Filter fabric is placed over the logs, covered with soil, and then vegetated.

Blast Pools

Salmonid production can be limited where the prevailing substrate material is bedrock. Suitable spawning gravels may accumulate in patches enabling adults to spawn successfully, but without pools there is limited cover and almost no refuge during high water periods. Blasting may be the only remedy available in such a circumstance.

Blasted pools should be located and sized so that they are self-scouring, otherwise they may fill with sediment. Blasted pools will not normally persist at depths any greater than that of the deepest natural pool in the stream; however, it may be cost effective to blast a deeper pool than required since it generally requires more drill holes (and explosives) to blast a shallow pool than to blast a deep pool of equal surface area. Blasting should only be performed by a certified blaster.

Figure 10.9 *Log bank cover.*

Maintenance

Materials placed in a stream to provide cover should be monitored closely during the first year, and periodically afterwards (especially following high flows). The materials should be checked for stability and structural integrity. Wood structures may have to be replaced because of decay and physical damage.

Structures intended to create pool cover are designed to be self-sustaining. The hydraulic action produced by these structures will both excavate and maintain pool habitat. Streambanks should be checked for erosion caused by altered flow patterns and areas of active erosion should be armoured with rock.

Blasted pools that do not maintain the desired depths due to in-filling may require additional work to produce the hydraulic conditions necessary to promote self-scouring. This may require further blasting or boulder placement.

Factors Influencing Cost

- fees for specialized professionals such as hydrologists, hydraulic engineers and blasters
- availability and cost of materials
- accessibility of the site to trucks and heavy machinery; helicopters may be the only means of transporting materials in some instances
- requirement for additional physical works (e.g. bank protection)
- blasting costs: number and dimensions of pools

Advantages of Technique(s)

- structures generally require little maintenance
- large organic debris may accumulate on instream structures, adding to total stream cover
- if materials are available at the site, costs are usually low
- valuable rearing habitat is produced while maintaining the stream's aesthetic qualities
- secondary benefits that may accrue include: gravel deposition; removal of fine sediments; increased aquatic invertebrate production; and streambank protection

Disadvantages of Technique(s)

- labour and material costs may be high, especially when projects involve the placement of large boulders
- structures that employ wood or organic debris will eventually require replacement
- if materials are not available at the site, costs can be high to transport them from another location
- construction may require the use of heavy machinery in the stream
- detrimental effects, such as downstream bank erosion, may occur as a result of habitat manipulation
- blasting is dangerous and can be expensive

Examples of Use

Queen Charlotte Islands, B.C.: Diagonal weirs constructed with single logs were placed in several streams on the Queen Charlotte Islands. The logs weirs provided both rearing habitat (pools) downstream and spawning habitat (gravels) upstream. The single log structure design was found to be superior to a multiple log (log arch) design.

Hyland Creek, Surrey, B.C.: A Hewlitt ramp was installed in this small tributary to the Serpentine River. The stream channel was armoured with rip rap to direct all flow over the structure. The Hewlitt ramp and banks failed during a peak flow event as a result of improper channel design.

Partial-Spanning Structures

Upper Keogh River, Vancouver Island, B.C.: Various deflector and boulder group designs were evaluated in the Upper Keogh River, Vancouver Island. The habitats created by these structures were used extensively by both steelhead trout and coho salmon juveniles. Boulder groups were found to be most cost effective. A helicopter was required to install some of the structures.

Coquihalla and Coldwater Rivers, B.C.: Deflectors and boulder groups were installed throughout the Coquihalla and Coldwater rivers during construction of the Coquihalla Highway. Organic debris has accumulated on some of the boulder groups, further increasing cover for salmonids.

Large Organic Debris

Coldwater River, B.C.: Fallen trees and brush were introduced into man-made rearing ponds in the Coldwater River to compensate for lack of natural riparian cover (Figure 10.10). The cover is heavily utilized by juvenile salmonids.

Nechako River, B.C.: Rootwad sweepers and brush cover have been installed in mainstem areas of the Nechako River. Log structures were installed to trap drifting woody debris and provide more mainstem complexing and cover.

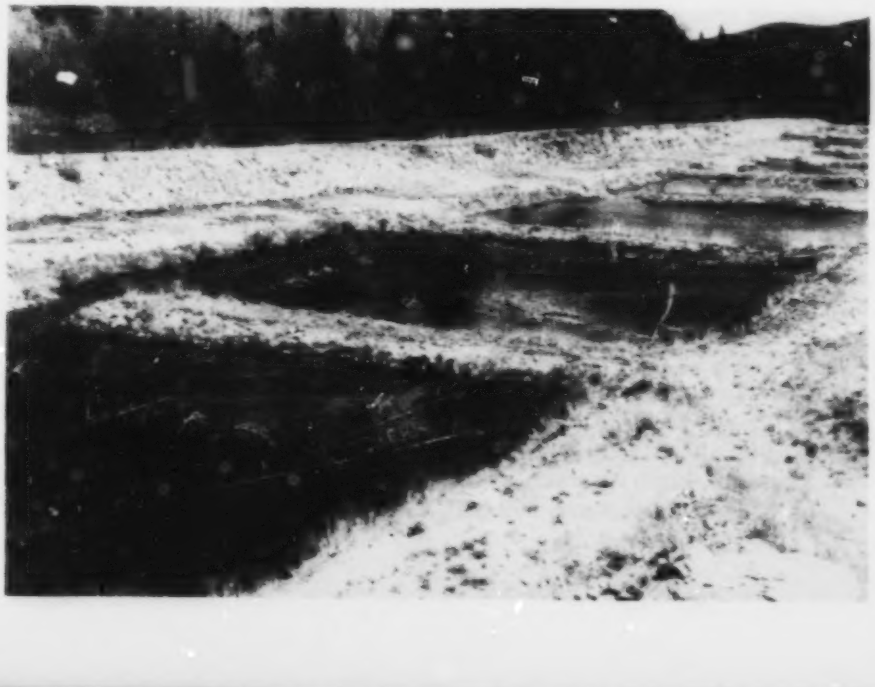


Figure 10.10 Large organic material provides excellent rearing habitat for juvenile salmonids. Coldwater River

Examples of Use

more mainstem complexing and cover.

Log Cover

Hoy Creek, Coquitlam, B.C.: A section of this stream that was relocated in 1981 included several log cover banks. Most of the structures were functioning well eight years after construction. Pool depth was maintained by scouring under those structures located at distinct bends in the channel. Pools at two of the log banks have filled in with sediment due to failure of deflectors and bank protection works upstream.

Enns Creek, Matsqui, B.C.: In 1989, four log cover banks were installed in a diversion channel. Subsequent monitoring indicates heavy use by salmonids.

Compensation Creek, Surrey, B.C.: Three log cover banks were installed in a channel diversion on a tributary to Bear (Mahood) Creek. Monitoring has indicated use of these structures by both rearing juveniles and spawning adults.

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11 *Off-Channel Development*

Introduction

Salmonid production can be increased through the improvement or creation of a variety of habitat types adjacent to the main stream channel. These habitat types include: side channels; groundwater-fed channels; and overwintering ponds. Juvenile steelhead and cutthroat trout and coho salmon utilize these habitats for rearing and overwintering. Adult salmon, in particular chum, prefer side and groundwater-fed channels for spawning.

Side channels are connected to the main channel at their upstream and downstream ends. Flow in a side channel fluctuates with the flow in the main channel.

Groundwater-fed channels are linked to the main channel at their downstream end only. Subsurface sources provide a stable flow of water of consistent quality.

Overwintering ponds may be fed by surface and/or subsurface water. Natural overwintering ponds are often connected to the main stream channel only by an outlet channel.

Application

Before commencing any off-channel development project, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

Off-channel habitat is created or enhanced where rearing and/or overwintering habitat is not sufficient to meet the needs of juvenile populations. Creation of off-channel habitat ameliorates mainstream problems such as flood, drought or ice formation. Groundwater fed spawning channels should only be constructed for species with no stream rearing requirements, or for stream rearing species for which adequate rearing habitat exists in the system to sustain the potential increase in juvenile production.

Flow availability and flood protection are essential components of an off-channel development. Creation and enhancement efforts should focus on those environments that provide both.

Various aspects of off-channel habitat creation and enhancement require substantial technical and financial resources. A feasibility study must be conducted to assess biological, hydrological and engineering constraints. It is for this reason that most off-channel projects are performed by or conducted under the direct supervision of resource agencies.

Design and Installation Guidelines

Groundwater sources must be identified and are usually sought as the primary water supply for blind side channel and overwintering pools. Subsurface sources usually produce high quality water; however, water quality must be assessed prior to proceeding with off-channel development. Groundwater flow rates and levels must be determined to ensure suitable flows and water depths can be maintained in the channels and ponds. Water levels must be monitored both in the off-channel project area and the main stream channel to determine whether or not a relation-

Design and Installation Guidelines

ship exists. Water level analysis will also determine the potential for back-watering and associated impacts, and provide criteria for the design of flood protection structures.

Fish access, flows, substrates and flood security must be addressed in the project plan. Fish access to the developed area is essential. An outlet channel possessing no migration barriers and adequate flows for the migration of adults and/or juveniles must link the enhancement/creation site with the main channel. Substrates must be appropriate for spawning and/or rearing. The project area must be protected from high flows in the main channel to ensure adequate refuge habitat and prevent wash-out of the project area.

Side Channels

The primary source of water for an open ended side channel is the main channel of the project stream. For this reason, water and flow conditions in the side channel will be closely related to those of the main river. Under natural conditions the side channel may experience variable flows ranging from low flows that can cause de-watering of redds, stranding of juveniles or creation of migration barriers, to high flows that scour spawning areas. The initial step in enhancing a side channel is to regulate the flow by constructing a control structure at the upstream entrance. A settling pond may also be required to reduce turbidity and intercept suspended sediments from the main channel. Once the sidechannel has been protected form scouring and a suitable flow has been established, the channel can be enhanced using standard improvement techniques. Figure 11.1 shows a side channel during the construction phase.

Groundwater Channels

Groundwater fed streams are much more stable than streams fed by surface water. Groundwater channels have been constructed primarily for the benefit of chum salmon spawners, which prefer slow flows and velocities and upwelling water. These channels are also ideal environments for rearing juvenile coho salmon and cutthroat trout. Improvement of groundwater-fed channels is an approach which generally provides long-term benefits at a reasonable cost/benefit ratio. A channel constructed for chum and coho salmon is shown in Figure 11.2.

Groundwater channels can be easily enhanced by increasing flow rate. Subsurface barriers can be installed to force groundwater to the surface. A simpler and equally effective approach is to deepen and lengthen the existing channel to intercept more subsurface flow. If the water table is near the ground surface, an entirely new channel can be created.

Initial site evaluation should include testing of the water quality and determination of the flow regime. Although the quality of groundwater is generally good, dissolved oxygen may be low. Pump testing should be conducted to measure probable flow rates.

Where water upwells, the channel can be widened to increase the spawning area. The channel gradient can be low (less than 0.2 percent) since incubating eggs are provided with intragravel flow by upwelling water. Where there is no upwelling, the channel should be steepened and narrowed to improve velocities, access and intragravel flow. Gravel placement or cleaning may be required if suitable gravel is not present. Selective use of gravel with a relatively high sand content may be advantageous for some species. For example, channels with sandy gravel will be utilized by chum salmon spawners but are relatively unattractive to rearing species (e.g. cutthroat trout) which normally prey on the chum fry.

Design and Installation Guidelines

Overwintering Ponds

Off-channel ponds provide ideal winter refuge from high flows and severe ice formation in the main river. The absence of such habitat may limit the production of stream-rearing salmonids, especially in coastal streams with widely fluctuating flows. Off-channel ponds also have considerable value as summer rearing habitat in systems prone to low flows and high temperatures. There are three approaches to increasing the amount of pond habitat: 1) improve existing overwinter-

Figure 11.1 Side channel during construction. Note gradient control weirs.

Figure 11.2 A groundwater channel constructed for chum and coho salmon.

Design and Installation Guidelines

ing ponds; 2) provide access to unused ponds; and 3) create new ponds.

The quality of habitat in existing ponds can be improved by increasing the flow of water. Flow augmentation can usually be accomplished by intercepting groundwater, as discussed above, or by diverting water from the main channel or a tributary. An increased flow may allow year-round use of the pond, where only seasonal use was available previously. Pond depth and surface area can be increased to accommodate more fish, increase food production, reduce predation and to prevent shallow water stranding or freezing to the bottom.

Access to a pond may be improved by increasing the flow, lowering the bed elevation of the outlet channel, installing gradient controls in the outlet channel, or installing fishways. Oxbow lakes, cut-off channels and abandoned quarries or gravel pits can be converted to productive overwintering or summer rearing habitat simply by providing access.

New ponds can be created by excavating depressions in areas where the groundwater table is near the surface or where water can be diverted from the main river or a tributary. If groundwater is to be the primary source of flow, its quality and probable flow rate should be determined prior to construction. During low flow periods, ponds should contain shallow areas (less than 1.0 metre depth) where food production is high, and deeper areas (1.0 - 3.0 metres depth) that provide refuge from predators. An outlet channel should be constructed to provide access.

An alternative approach to increasing pond habitat involves the creation of new ponds by blasting large pools (up to 10 metres in diameter) at intervals along an existing tributary channel (Figures 11.3 and 11.4).

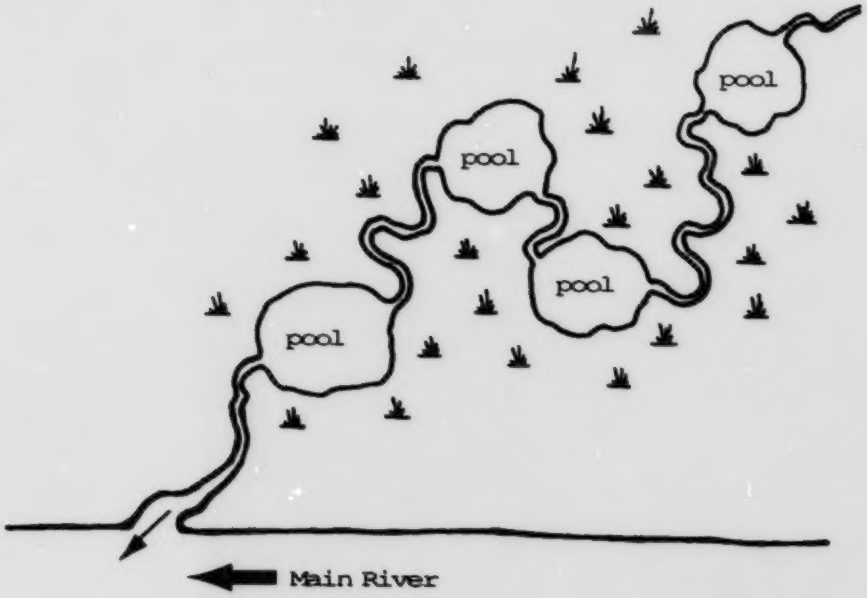

***Figure 11.3** "Beaded channel" created by blasting pools along a low gradient tributary stream (after Cedarholm et al. 1988).*

Design and Installation Guidelines

Figure 11.4 *This pool was created using explosives.*

Maintenance

Unless elaborate water intake systems are employed, off-channel habitat that relies on water diverted from a main river or a tributary will require regular maintenance of its intake and water conveyance system. Most maintenance problems arise from debris accumulation and/or silt in the system. Deposition of sediment in the channel or pond may require substrate cleaning (see Chapter 7).

Owing to the stability of flows, groundwater-fed systems typically require very little maintenance.

Factors Influencing Cost

- creation of new habitat is generally more costly than improvement of existing habitat; the more complex the design (number of features such as dykes, diversions, etc.) the greater the cost
- assessment of potential flow rates from groundwater sources may require lengthy monitoring programs
- accessibility of the site to heavy machinery
- amount of flood protection required
- availability and cost of materials such as gravel and rock

Advantages of Technique(s)

- off-channel habitat can contribute significantly to the production of salmonids, particularly in streams which experience severe winter flooding, ice formation, or summer droughts
- protected off-channel areas are not affected by flooding in the main river
- flow is quite stable in off-channel areas relative to that of the main channel; the quality of habitat in off-channel areas can; therefore, be more easily maintained

Disadvantages of Technique(s)

- developing off-channel habitats can be quite costly, especially if elaborate flood protection, water intake/ conveyance or silt settling facilities are required
- extensive pre-development monitoring may be required to determine the quality and potential flow rates of groundwater sources
- some off-channel habitats may become de-watered during summer months

Examples of Use

Side Channels

Judd Slough, Squamish, B.C.: A dyke was constructed in 1967, then upgraded in 1975, to provide protection from Squamish River floods. Although primarily groundwater-fed, water is diverted into the channel through an intake structure in the dyke to augment flows during the chum salmon spawning period. Gravel has been added to Judd Pond to increase spawnable area.

Groundwater Channels

Alouette River, Maple Ridge, B.C.: A groundwater channel for chum and coho salmon was constructed in 1989.

Overwintering Ponds

Coldwater River, B.C.: Off-channel ponds were constructed as compensation for habitat lost during the construction of the Coquihalla Highway. The ponds are groundwater-fed. Large organic debris was installed in some pools; riparian vegetation was planted on others. All pools are used by coho juveniles.

Bonanza Creek, Queen Charlotte Islands, B.C.: Explosives were used to create rearing habitat by blasting pools into soft sediments on a tributary of Bonanza Creek. Loss of riparian habitat was more than compensated for by increases in deep water habitat. Some infilling of the pools with fine sediments have been reported .

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12 *Food Production*

Introduction

Food availability can be a limiting factor in the production of stream- and lake-rearing salmonids. Freshwater production can be increased by augmenting the supply of food. In addition to increasing numbers, this technique contributes to the production of larger, healthier smolts with the ultimate objective of achieving higher marine water survivals and adult escapements. Lake enrichment has been undertaken for several decades and is becoming relatively well understood. More recently, research efforts have focused on stream enrichment.

The abundance of plants and animals within the stream ecosystem that comprise the lower trophic levels of the food chain, (e.g.: algae, fungi, bacteria and phytoplankton) is dependent on the availability of nutrients. Generally, the higher the nutrient concentration, the greater the abundance of lower trophic organisms. These organisms are consumed by higher trophic organisms (e.g.: zooplankton and benthic invertebrates) that are often important in the diet of juvenile salmonids.

Most enrichment projects focus on enhancing the production of lower trophic organisms by increasing available nutrients through the application of inorganic fertilizers. Organic enrichment with leaf matter has also been attempted. Some programs have bypassed these indirect approaches and augmented existing food supplies through the direct introduction of commercially prepared fish food.

While lake enrichment projects have met with relative success, problems have been encountered in stream enrichment, most notably the lack of overwintering habitat to sustain increased populations. The failure of these projects emphasizes the need to properly diagnose limiting factors.

Many of the approaches presented in this chapter are complex and require a high level of technical expertise. Most are considered experimental, and accordingly, have only been approved as research studies under the direct supervision of fisheries resource agencies.

Application

Before commencing any enrichment projects, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

Permits and approvals are required and may be difficult to obtain due to the experimental status of these techniques.

The effects of artificial enrichment on aquatic systems are not fully understood. After twenty years of study, lake enrichment procedures are only partially refined for fast-flushing, coastal lakes on which the studies have been based. The applicability of enrichment to large, slow-flushing interior lakes has yet to be assessed. Stream enrichment techniques have only been defined for those streams where they have been evaluated. Enrichment of aquatic systems for the purpose of food production is still considered experimental, and requires further research and refinement. Also, enrichment is only appropriate when nutrient availability or food production is the limiting factor.

Coastal streams tend to have lower natural concentrations of nutrients than interior streams due to the higher runoff and the different geological characteristics of coastal watersheds. Enrichment, therefore, has greater potential for increasing productivity in coastal streams.

Design and Installation Guidelines

Enrichment and supplemental feeding should be conducted when juvenile salmonids have the greatest potential for growth (April to October).

Lake Enrichment

Most lake enrichment projects have focused on the production of sockeye salmon. Aqueous solutions of inorganic nitrogen (N) and phosphorus (P) are applied weekly during the growing season from either a boat/barge or aircraft (Figure 12.1). For coastal lakes, nitrogen and phosphorus are generally applied in ratios ranging from 10:1 to 20:1 respectively. Higher proportions of nitrogen (35:1 N:P) have been used to minimize the incidence of algal blooms in some lakes. Estimated optimal loadings for fast-flushing coastal lakes are about 60-90 mg N and 4-6 mg P per m^2 per week.

In general, lake production of both primary organisms (e.g. phytoplankton) and secondary organisms (e.g. zooplankton) is increased by enrichment. Most of the lakes treated to date have produced larger sockeye smolts. Larger smolts contribute to higher marine survivorship which should increase adult **escapement**.

Stream Enrichment

Streams can be enriched with either organic or inorganic materials. The results of limited research indicate that both techniques can increase salmonid production. Other impacts have yet to be adequately assessed; although, these include effects on competitors and predators and their impact on the target species, areal extent of effectiveness, effects on downstream water users and impacts on substrates used for spawning and incubation.

Organic Enrichment

Organic materials have been added experimentally to stream substrates in efforts to increase the biomass of aquatic invertebrates. Examples of materials that have been used include grains, soybean, deciduous leaves (willow and alder) and dissolved sucrose. Application has successfully increased production of primary organisms (algae, bacteria and fungi) that are important dietary components of fish food organisms.

Figure 12.1 Aircraft can be used to apply an aqueous solution of inorganic fertilizers to lakes.

Design and Installation Guidelines

Organic enrichment should commence in the spring and continue through to early fall. Organic material should be soaked in hot water prior to application to make it less buoyant and in the case of grains, to prevent germination. Organic supplements are usually applied manually.

Inorganic Enrichment

Concentrations of phosphorus and nitrogen in a stream can be artificially elevated by adding soluble fertilizers. Addition of inorganic fertilizers should commence early in the salmonid growing season. The nutrients are soluble and are rapidly carried out of the treatment area. In order to maintain concentrations at the target level, application must be frequent, often necessitating the use of automated supply systems (Figure 12.2). Nutrients in solution must be added almost continuously: solid fertilizer pellets are introduced on regular intervals (e.g.. hourly). Application rates may need to be adjusted to account for variations in streamflow.

The loading rate and formulation which will be most effective is site specific. Recommendations must be based on the results of field trials conducted over several years to examine the response of invertebrates and fish to various application rates and formulations. Alternatively, bioassays can be performed on fish to determine optimum levels for growth and condition. Loading levels should be sufficient to elevate nutrient concentrations for some specific (target) distance downstream.

Supplemental Feeding

Increased salmonid production can be achieved by directly increasing the food supply. Daily feedings of either commercially prepared fish food or pre-frozen euphausiids (marine shrimp) have resulted in several-fold increases in fish biomass.

Fish food can be applied either by hand (Figure 12.3) or by automatic dispensers .

Organic material and prepared foods are usually applied manually or by using simple spreaders. Maintenance requirements for these treatments are negligible. Automated equipment is often required for inorganic materials. This equipment should be inspected regularly to ensure that material is applied as scheduled and to refill dispensers. Nitrate fertilizer is very active and corrosive, therefore, dispensing equipment must be constantly maintained (e.g.: washed after use).

Monitoring is a critical component of stream enrichment or supplemental feeding programs, especially in light of the experimental nature of these techniques. Particular attention should be paid to determining the optimal nutrient levels required to achieve the desired production levels.

Design and Installation Guidelines

Figure 12.2 Automated supply systems, such as these used on the Nechako River, provide regular application of nutrients.

Figure 12.3 Manual application of food in a small stream.

Factors Influencing Cost

- organic enrichment is a low cost approach, involving the application of relatively inexpensive materials on a periodic basis; supplemental feeding is more expensive as treatments are usually performed daily
- inorganic enrichment often necessitates the need for costly automated feeders or supply systems
- lake enrichment is expensive due to the large volumes of fertilizer required and the requirement of either a large boat, barge or aircraft
- site accessibility is a factor to consider in selecting the method of application for lakes; aircraft may be necessary for some lakes with no road access
- the amount of material required for organic enrichment or supplemental feeding is proportionate to the stream or lake area being enhanced; inorganic enrichment at a fixed point on a stream can increase production of salmonids for several kilometres downstream
- pre-treatment nutrient deficiencies and desired nitrogen and phosphorus levels will affect loading rates which in turn determine the quantity of fertilizer required

Advantages of Technique(s)

- significant increases in the number and/or size of juvenile salmonids can be achieved by lake/stream enrichment and supplemental feeding
- benefit-cost ratios for these techniques, particularly inorganic enhancement, are quite high relative to many other habitat enhancement techniques
- increased marine survival rates and adult escapements are possible; the lake enrichment research program results appear to support these conclusions
- these techniques are considered experimental: much more research is required before these techniques become standardized

Disadvantages of Technique(s)

- extensive monitoring must be conducted in conjunction with each stream enrichment or supplemental feeding project in order to assess pre-treatment, treatment and post-treatment conditions
- there are no permanent, or even long term benefits; increases in fish production will occur only as long as the program is continued
- the production of fish cannot be increased above the carrying capacity of the stream as determined by other habitat parameters such as overwintering capacity
- negative impacts such as eutrophication (degraded water quality) and increased populations of predatory species may occur
- downstream water users may be affected by altered water chemistry

Examples of Use

Organic Enrichment

Big Qualicum River, Vancouver Island, B.C.: Cereal grain and soybean were added at a rate of 500 mL/m² to gravel in 12 parallel wooden troughs in a side channel of the river. Weight and number of invertebrates were increased 1.5 - 2.9 and 1.4 - 1.9 respectively in enriched troughs.

Inorganic Enrichment

Keogh River, Vancouver Island, B.C.: Four 300-metre sections of the river were used to assess treatments of organic matter and inorganic fertilizers. The weight of coho fed organic matter (rolled oats) was 58% greater than that in the control section. Fertilizer (nitrogen-phosphorous) additions increased coho fry weight 82%. The weight of steelhead trout differed little between organic treatment and control sections, but increased in control sections by 67%. Investigators concluded that inorganic enrichment produces greater benefits for growth of salmonids than organic enrichment in nutrient-deficient streams.

Nechako River, B.C.: A pilot study was initiated on a side channel of the river in 1989 to assess the feasibility of inorganic enrichment in the mainstem. Both nitrogen and phosphorus were found to be deficient. A ratio of 4:1 (N:P) was used to enrich the system. Further studies will assess the effects on juvenile chinook and other species, cost effectiveness of enrichment and refinement of loading ratios and rates to elevate apparent P concentrations 5-fold for a distance of 4-5 kilometres downstream.

Supplemental Feeding

Lower Sandy Creek, Vancouver Island, B.C.: Supplemental feeding was conducted in a small experimental stream. Pre-frozen euphausiids were fed to stocked coho fry. A 6-fold increase in biomass was realized. A decline in biomass to pre-treatment levels was attributed to limited overwintering habitat.

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13 *Obstruction Removal*

Introduction

Natural obstructions may restrict or completely block upstream migration of salmonids. There are four common types of naturally occurring migration barriers . These include: falls and inclines; rock slide;, log/debris jams; and beaver dams.

Falls and inclines occur on bedrock-controlled stream sections. A fall occurs where the stream gradient changes abruptly to near vertical. Low falls can be jumped without difficulty if a plunge pool of sufficient depth exists. An incline is a steep section of bedrock streambed where water velocities exceed the maximum swimming speeds of salmonids (Table 13.1). As each species of salmonid differs in its swimming abilities, falls or inclines that are barriers to one species may not be to another. Falls and inclines may also be impassable under certain flow conditions but passable under others.

A rock slide usually introduces large material into the stream channel. Slides often decrease passage area and increase channel gradient. These changes in channel geometry often produce high water velocities or jumps that are impassable to salmonids.

Log and debris jams are very common in Pacific coast streams. Trees, branches and other woody debris find their way into stream channels through natural processes (wind, fire, floods, etc.) and human activity (timber harvesting, land clearing, etc.). However, only a small percentage of all log and debris jams constitute total migration barriers or cause significant degradation of habitat. Instream debris may contribute significantly to total instream cover. The net benefit of debris removal must be carefully assessed.

Beaver dams built across small streams can prevent or delay adult salmonids from reaching spawning habitat further upstream. There is usually no concentration of flow over the crest of the dam and no plunge pool below. Consequently, migrating fish must wait for high flows to provide them with the depth of water necessary to proceed beyond the barrier. Ponds created behind beaver dams.

However, provide excellent summer and winter rearing habitat for juvenile salmonids. The net benefit of dam removal must be carefully assessed.

Fishways (Chapter 15) offer an alternative approach to resolution of fish passage problems at some obstructions. Culverts and associated passage problems are discussed in Chapter 14.

***Table 13.1** Swimming speeds of some salmonid species in metres per second (adapted from Bell, 1986).*

Fish Species	Cruising Speed	Sustained Speed	Burst Speed
Chinook	0 - 1.0	1.0 - 3.3	3.3 - 6.8
Coho	0 - 1.0	1.0 - 3.3	3.3 - 6.6
Sockeye	0 - 1.0	1.0 - 3.1	3.1 - 6.3
Pink*	0 - 0.8	0.8 - 2.3	2.3 - 4.6
Chum*	0 - 0.8	0.8 - 2.3	2.3 - 4.6
Steelhead	0 - 1.4	1.4 - 4.2	4.2 - 8.1
Cutthroat	0 - 0.8	0.8 - 1.8	8.0 - 4.2

* - estimated from leap heights (Orsborn, 1985).

Application

Before commencing any project involving the removal or alteration of instream obstructions, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

An obstruction should be removed or altered only if it prevents or harmfully delays salmonid migration or denies access to unused but potentially productive habitat. All obstructions should be assessed by experienced biologists to ensure that a passage problem truly exists and that removal will have the desired biological and hydrological benefits. Where blasting is required, use only certified blasters approved by resource agencies.

Project timing is very important. Work should not be conducted during spawning, incubation or critical juvenile rearing periods.

Design and Installation Guidelines

Falls and Inclines

Falls and inclines can be made passable by re-contouring the streambed to create hydraulic conditions within the swimming and jumping capabilities of migrating salmonids. However, this approach can be quite complex since falls and inclines occur predominantly in bedrock. Structural changes require the selective removal of bedrock by blasting or breaking. Blasting requires considerable skill and is extremely dangerous. The obstruction should be assessed by both biologists and a certified blaster. Prior to blasting, the stream within the blast area should be dewatered and all fish salvaged. Fracturing involves drilling holes into the bedrock and then splitting off fragments by driving special rock wedges into the holes. Non-explosive demolition agents have also been used. The agents are placed in holes drilled in the bedrock. As the non-explosive demolition agent absorbs water, they exert tremendous outward pressure that eventually fractures the rock.

Salmonids are unable to ascend a small waterfall if there is not a plunge pool of sufficient depth below the obstruction. Resolving the passage problem at a fall may be accomplished either by decreasing the height of the jump or increasing the depth of the plunge pool (Figure 13.1). The height of the jump must not exceed 1.25 times the depth of the plunge pool. Strong currents in the plunge pool produce a wave of upward flowing water that fish utilize for additional jumping lift. If pool depth is inadequate, this standing wave may be located too far from the jump to be of any benefit to the fish.

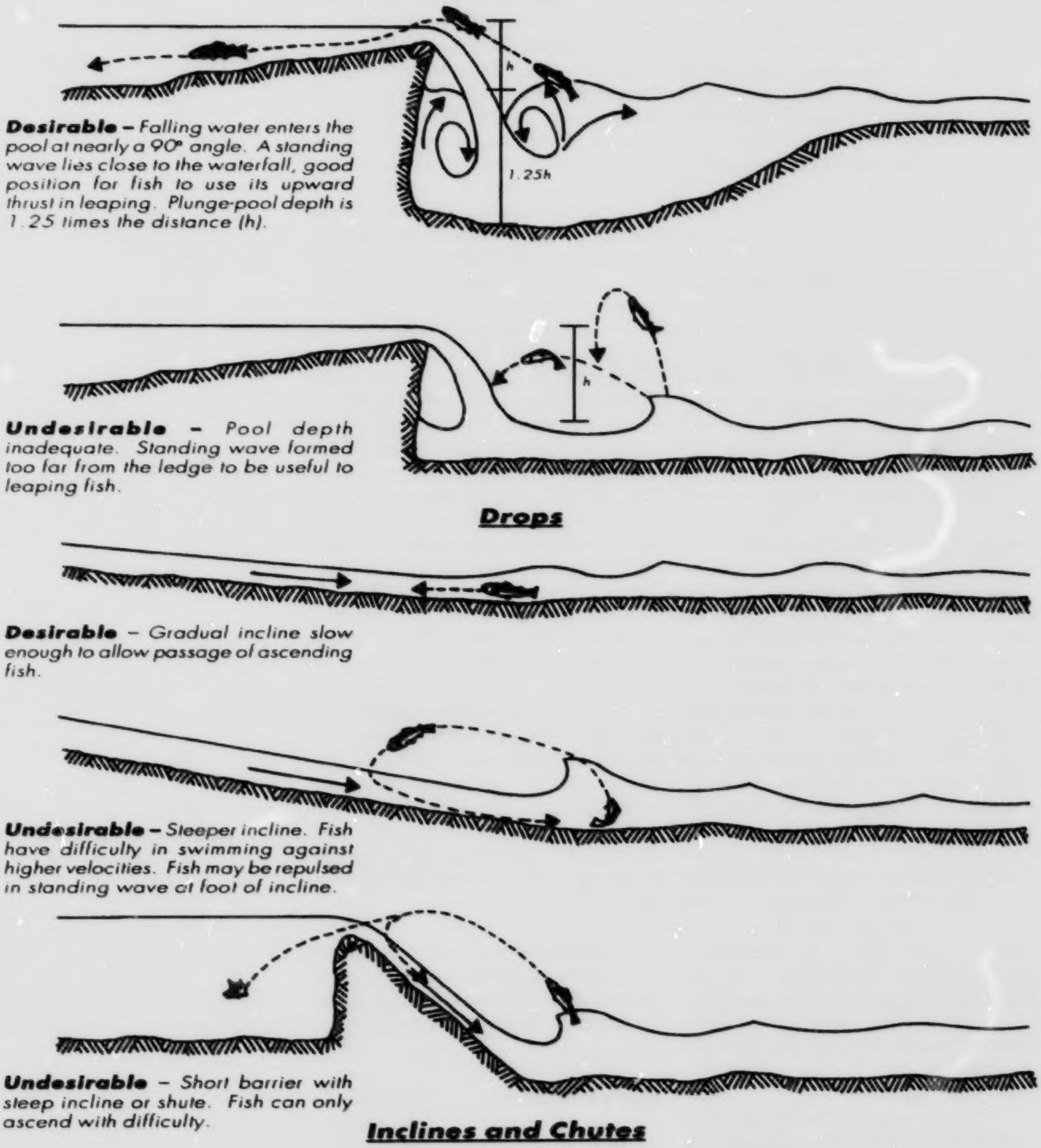
An incline offers little resistance to flow and therefore contributes to high water velocities. It is a barrier to fish migration if it is of such a gradient and/or length that the water velocities exceed the swimming abilities of the fish. Inclines can be reshaped to permit passage by blasting a series of pools and steps into the bedrock.

Passage through a series of falls or long inclines may be more effectively provided by a fishway. This alternative should be considered during initial project planning.

Rock Slides

Rock slides invariably occur without warning. When a rock slide blocks migrating fish, the slide must either be removed immediately or steps must be taken to

Design and Installation Guidelines



Desirable – Falling water enters the pool at nearly a 90° angle. A standing wave lies close to the waterfall, good position for fish to use its upward thrust in leaping. Plunge-pool depth is 1.25 times the distance (h).

Undesirable – Pool depth inadequate. Standing wave formed too far from the ledge to be useful to leaping fish.

Desirable – Gradual incline slow enough to allow passage of ascending fish.

Undesirable – Steeper incline. Fish have difficulty in swimming against higher velocities. Fish may be repulsed in standing wave at foot of incline.

Undesirable – Short barrier with steep incline or shute. Fish can only ascend with difficulty.

Figure 13.1 Modification of falls and inclines to improve passage conditions for salmonids (Adapted from White and Brynildson, 1967; diagrams after Stuart,1964).

Design and Installation Guidelines

capture and transport the fish past the barrier.

Slide removal techniques vary depending on the volume of material to be moved, the size of the largest rocks and site accessibility. Small slides can be removed manually by lifting or rolling material clear of the stream. Wheelbarrows, shovels and pry bars are useful tools in removing such small obstructions. Large rocks can be broken into smaller fragments with explosives, non-explosive demolition agents, rock drills and wedges. Material can be placed in a sling and moved clear of the slide using a winch or block and tackle. Where access is available, large equipment such as bulldozers may be used to clear the jam. In less accessible areas, material can be loaded into slings and moved with a helicopter or transported by barge (Figure 13.2).

Timing is an essential element of rock slide removal. Migrating adult salmonids must be provided with access immediately. Clearing of a narrow, low velocity channel around the main slide should be the first priority. If this is not feasible, arrangements should be made to capture and transport the fish to a point well above the slide area. Avoid removal of slides during spawning and incubation periods.

Log/Debris Jams

All log/debris jams should be critically assessed prior to removal. It must either completely block or impede passage, or cause sedimentation of gravels and/or bank erosion. Otherwise, log and debris jams should be left in place as they provide important cover for rearing juveniles (Figure 13.3).

Several techniques can be applied to remove log and debris jams (Figure 13.4, 13.5). Small jams can be removed by cutting large logs and branches into small pieces using chainsaws. The material is then removed to an upland disposal site. Whole logs can be pulled clear of a jam with either a winch or block and tackle. Cables can be attached to the log with a choker (short loop of cable or chain) or a grappling hook. Large log jams can be quickly removed by a commercial log yarder. Logs are removed by hooking them up to an overhead cable and lifting them clear of the jam. A log yarder and operational crew are generally available only through logging contractors.

Blasting can be used to remove debris. It requires specially trained personnel. This approach involves weakening the jam prior to detonation by sawing through the logs that anchor the jam to the streambed and to the banks. Stream dewatering and fry salvage must be undertaken prior to blasting. Debris is removed to an upland disposal site.

Often large amounts of fine sediments accumulate behind log or debris jams. After dewatering the site, the sediment should be excavated and removed to an upland disposal site. The disposal site should be above the high water mark to prevent the material from being reintroduced to the watercourse. If this is not feasible, movement of material can be controlled by installing sediment curtains or sandbags downstream. Sediment can then be removed with an excavator.

Beaver Dams

Beaver ponds provide excellent summer and winter habitat for juvenile salmonids. It is imperative that only those beaver dams that prevent upstream migration be removed (Figure 13.6). Few completely block migration at all flows. Beaver ponds often augment downstream flows during periods of drought. The benefits of dam removal should be weighed against existing habitat values.

Beaver dams are constructed with twigs, branches and mud. Removal can usually be accomplished by hand or with

Design and Installation Guidelines

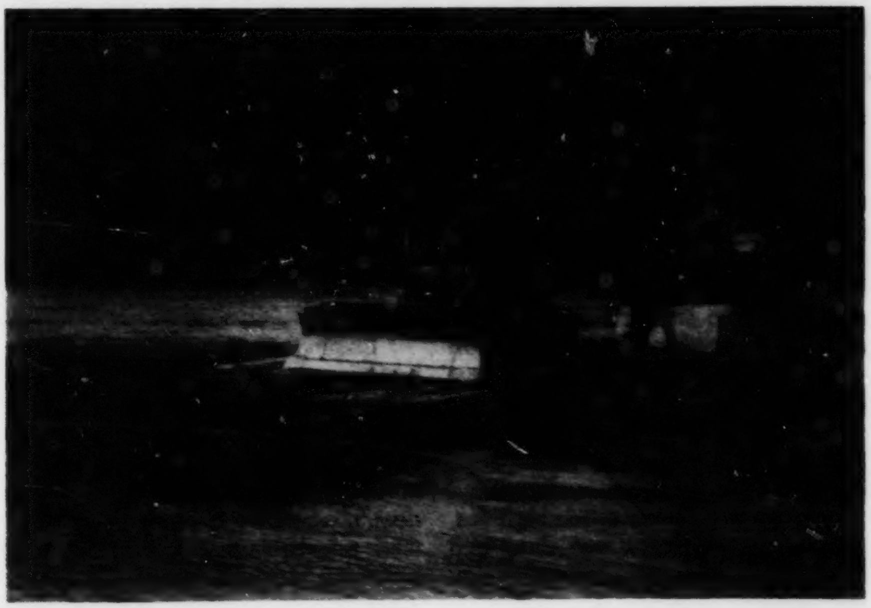


Figure 13.2 Site accessibility is often a factor in abstruction removal. This bulldozer was barged to the work site.

Figure 13.3 Small log jams such as this may impede fish passage.

simple tools. All material should be cleared down to the original streambed. Care must be taken to remove all anchor-sticks that serve as the foundation of the dam. If these are left in place, they will provide excellent anchorage for a replacement structure. Beavers will work diligently to replace an active dam which has been removed.

It may be necessary to remove a dam several times before the beavers abandon the site. Beavers can be deterred from rebuilding a dam by installing flashing road construction lights, suspending plastic bottles in the current to bang together, or applying commercial beaver repellents. It may be necessary to trap and remove the beavers from the area entirely.

Design and Installation Guidelines

Figure 13.4 Small debris jams can be broken up with chainsaws and emoved manually.

Figure 13.5 Larger jams can be removed with heavy machinery.

Beavers often block migration by plugging the upstream entrance to a culvert. Commercial products are available that prevent beavers from blocking culverts or that make dam removal simple. Wire mesh culvert protectors keep beavers away from the culvert entrance. Hinged metal grates can be placed over the entrance and pulled upwards to remove dams.

In many instances the most cost-effective approach is to manage the beaver dam without actually removing it or the beavers. Coordinate a management program with fisheries officials to permit fish passage throughout the migration period.

Design and Installation Guidelines

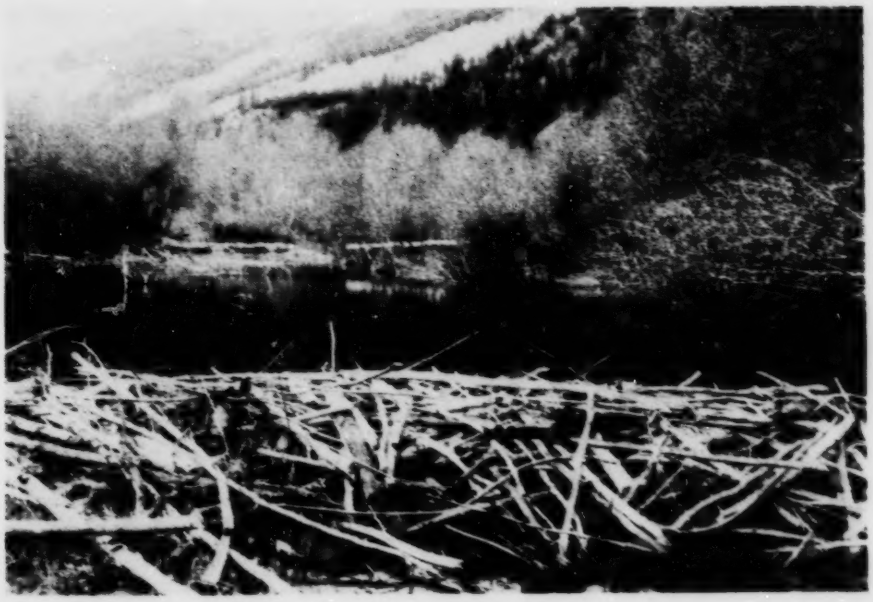


Figure 13.6 The impoundment behind this beaver dam provides excellent summer and winter refuge areas for rearing juvenile salmonids.

Maintenance

In general, there is no maintenance involved in obstruction removal. However, new obstructions may occur in the general vicinity of the removed barrier. Land slides, log/debris jams and beaver dams that occur in a given reach usually indicate that the area is susceptible to obstruction formation. Periodic inspection of obstruction removal sites is, therefore, recommended. Such inspections will identify whether any further remedial actions will be required.

Factors Influencing Cost

- accessibility of the site to crews and heavy machinery
- contracting/rental costs for heavy machinery, materials and speciality crews (e.g. blasters)
- amount and type of material to be removed

Advantages of Technique(s)

- access can be restored or improved so that established runs are maintained or strengthened
- sections of previously unused stream habitat can be opened and brought into production
- sedimentation and bank erosion associated with obstructions will be reduced

Disadvantages of Technique(s)

- establishment of an anadromous fishery above a previously impassable barrier may negatively affect an existing resident fishery by introducing competitors, predators and disease
- removal of log/debris jams and beaver dams may produce a loss of rearing habitat, particularly critical overwintering habitat
- obstruction removal may be accompanied by a release of sediment which may adversely affect downstream habitat
- obstruction removal may require special equipment and personnel, and be relatively expensive
- some obstruction removal techniques require site dewatering and fry salvage

Examples of Use

Falls and Inclines

Salmon River, Vancouver Island, B.C.: In 1978, steps were blasted into bedrock falls. Steelhead now migrate beyond the falls and utilize previously inaccessible habitat.

Fraser River, Saddle Rock, B.C.: During the winter of 1987, a bypass channel was blasted and excavated at Saddle Rock in the Fraser Canyon to eliminate a velocity/gradient barrier to pink and sockeye salmon.

Rock Slides

Tahltan River, B.C.: In 1964, a rockslide created a barrier to upstream migrating sockeye salmon. The slide could not be removed immediately, so adult sockeye salmon were captured and airlifted by helicopter to a point upstream of the obstruction. The slide was later cleared.

Log/Debris Jams

Silverhope Creek, B.C.: A large log jam was removed in 1987 as it threatened to cause a washout of the road immediately downstream. Logs and woody debris were removed with a log skidder and later burned.

Weaver Creek, B.C.: In 1980, a debris jam over 400 metres in length accumulated in the creek during a flood. The jam blocked the entrance to the spawning channel and necessitated immediate removal with heavy equipment.

Beaver Dams

Chilqua and Whonnock Creeks, Mission, B.C.: Active beaver dams were removed by hand in 1987 to permit upstream migration of chum and coho salmon in these two small tributaries of the Fraser River. On both streams, dams were removed twice before beavers abandoned efforts to reconstruct at the same site.

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14 *Culverts*

Introduction

Most culverts are installed as less expensive alternatives to bridges where roads, highways and railways intersect stream courses. Properly designed and installed, they efficiently convey water downstream and permit unimpaired passage of migrating salmonids upstream. Culverts that are improperly designed and/or installed can delay or block upstream movement of fish (Figure 14.1).

Culvert installations in salmonid-bearing streams are closely monitored by federal or provincial fisheries agencies to ensure that the installations conform with fish passage criteria (Table 14.1). Detailed culvert design and installation procedures are beyond the scope of this document, therefore, discussion is focused on resolution of fish passage problems at existing, older culverts. The vast majority of passage problems at culvert sites relate either to high water velocities in the culvert or creation of an impassible vertical drop at the culvert outlet. Baffles installed on the bottom surface of a culvert will afford easier passage by reducing velocities and increasing depths. An outlet pool built at the downstream end of the culvert will eliminate the drop and provide favourable entrance conditions.

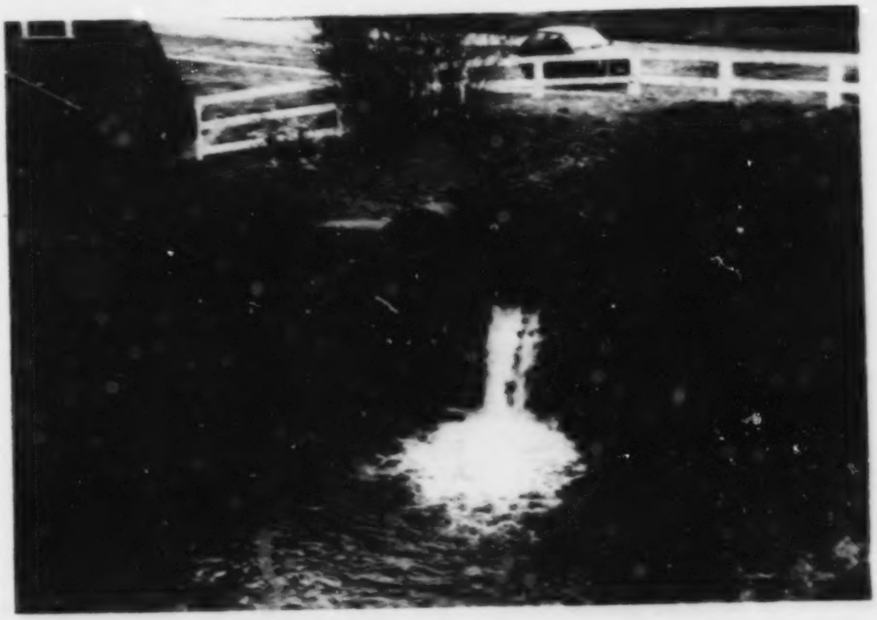


Figure 14.1 The drop at the culvert outlet is a barrier to fish migration.

Introduction

Table 14.1. Fish migration requirements and general design criteria for culverts (Dane, 1978a).

A. Fish Migration Requirements.

1) Velocities: average velocities should not exceed:
   a) 1.2 m/sec for culverts less than 24.4 m in length.
   b) 0.9 m/sec for culverts greater than 24.4 m in length.
   c) culverts greater than 61 m in length, consult DFO.

2) Water Depth: should not be less than 0.23 m at any point within the culvert.

3) Water Surface Profile: any sudden drop in the water surface profile at any point within culvert influence should not exceed 0.31 m.

4) Migration Delay: during the fish migration period, the length of time during which the foregoing conditions are not met must not exceed 3 consecutive days in an average year.

B. Design Criteria.

1) Capacity: all culvert facilities should be designed to accommodate the 100 year flood, defined as the discharge event having a recurrence interval of 100 years. During that flood event, headwater depth must not exceed the culvert height.

2) Slope: the effective slope* should not exceed:
   a) 0.5% for culverts greater than 24.4 m in length (unless compensation is made by addition of baffles).
   b) 1.0% for culverts less than 24.4 m in length (unless compensation is made by addition of baffles).
   c) 5.0% under any circumstance, even with baffles.

3) Installation Below Grade: the culvert should be installed so that the bottom of the structure is at least 0.31 m below the natural grade-line of the stream.

4) Culvert Baffles: if the slope of the culvert exceeds the criteria outlined above, baffles should be constructed in the culvert barrel.

5) Outlet Pool and Tailwater Control: an outlet pool with tailwater control capabilities should be constructed at the culvert exit.

6) Multiple Installations: when more than one culvert is provided at the crossing site, fish passage criteria need only be applied to one of the culverts. The culvert to which fish passage criteria are applied should be at least 0.31 m lower than the other(s).

* Effective slope is defined as the mean gradient of the water surface profile between a point located at the culvert inlet and the tailwater control point below the culvert outlet.

Application

Before commencing any culvert modification in a stream or river, contact the Department of Fisheries and Ocean's or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

The design and installation of baffles and outlet pools requires considerable expertise and should not be undertaken without the guidance of a qualified engineer or technician.

Baffles are installed in culverts where water velocities are too great or depths are too shallow to permit passage of fish. Outlet pools are constructed where an impassable drop exists at the outlet of the culvert.

Design and Installation Guidelines

Culvert Baffles

Culverts are constructed from relatively smooth materials (concrete, corrugated metal or wood) that offer little resistance to flowing water (various culvert types and associated concerns are shown in Figure 14.2). Consequently, mean water velocities tend to be much greater in the culvert than in the natural stream channel. A velocity barrier occurs when the water velocities in the culvert exceed the swimming abilities of the fish (see Chapter 13, Table 13.1). Water depths tend to be decreased through a culvert that may also be a barrier to migrating fish. As a remedial approach, baffles can be installed in culverts to decrease velocities and increase depths to permit fish passage.

Baffles are low weirs that are attached to the bottom of a culvert and extend partially or completely across the culvert. The "offset" baffle design, favoured for coastal streams, uses pairs of baffles (Figure 14.3). On one side of the culvert, short baffles are attached perpendicular to the culvert walls and extend out to about the middle of the culvert. Opposite them, longer baffles are attached at 30 degrees from the culvert walls facing upstream. The height of the baffles should be between 0.31 and 0.61 metres.

Baffles are generally made of either treated wood or concrete. Wood is easiest to use in square culverts; concrete has the advantage of conforming to irregular surfaces (e.g. corrugated metal). Baffles are anchored by means of reinforcing steel or bolts welded to metal culverts, or rock bolts fastened to concrete.

Outlet Pools

A drop at the downstream end of a culvert may result from poor design and/or installation. The exit of the culvert may have originally been set too far above the streambed, or the streambed may have been lowered by erosion. Fish will not be able to migrate upstream if the drop is too great or there is no plunge pool from which to jump from.

An outlet pool with a control weir will back-flood the culvert to provide an adequate depth of water for fish passage. The outlet pool will also provide a resting area for fish. Both the length and width of the pool should be twice the diameter of the culvert and the depth should be at least 0.6 metres (Figure 14.4). Multiple weirs, each with a notch to concentrate low flow, may be necessary to overcome steep grades from the culvert outlet to the streambed (Figure 14.5). Outlet pools are typically constructed with large rocks and riprap, although concrete and wood can also be effective.

Design and Installation Guidelines

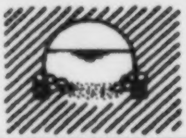
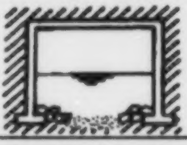
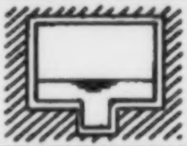
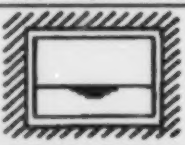
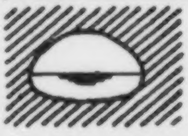
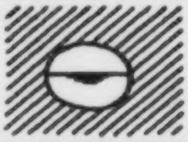
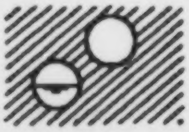
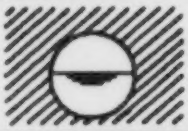
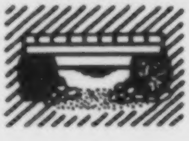
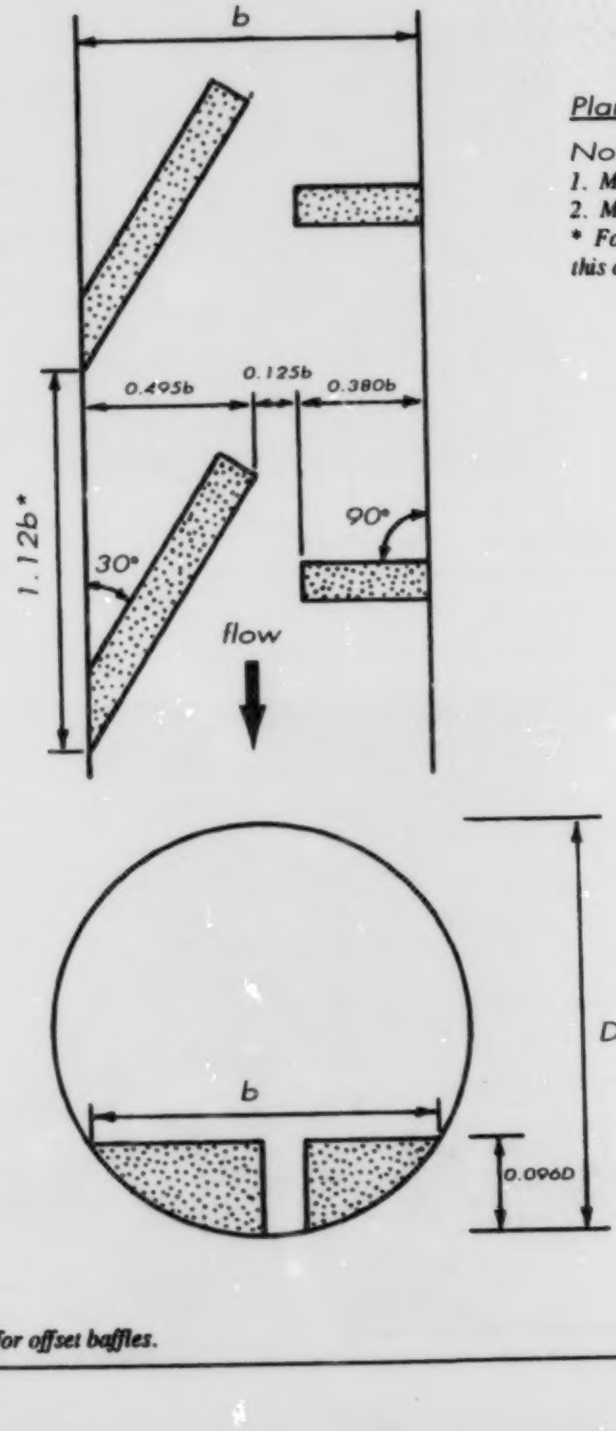
Type of Culvert	Fisheries Considerations	Hydraulic Considerations
	- If properly designed and installed, it does not limit fish passage. - Retains natural stream substrate. - Water velocities not significantly changed.	- Wide bottom area enables passage of high flows while minimizing increases in flow depth. - Large waterway opening for low clearance installations.
	- If properly designed and installed, it does not limit fish passage. - Retains natural stream substrate. - Water velocities not significantly changed.	- Can be designed to maintain normal width of the stream channel. - When a large end area is required in low fill, box culverts can be put side by side.
	- Can be designed to provide fish passage. - Trough concentrates water maintaining fish passage even at low flows. - Baffles can easily be installed.	- Can be designed to maintain normal width of the stream channel. - When a large end area is required in low fill, box culverts can be put side by side. - Note: Trough can fill with bed load material and create maintenance problems.
	- Acceptable for use with approved design in the stream channel. - Limits fish passage during low flow due to decreased flow depths. - Baffles can easily be installed.	- Can be designed to maintain normal width of fish bearing streams. - When a large end area is required in low fill, box culverts can be put side by side.
	- Acceptable for use with approved design in fish bearing streams. - Can be designed to retain some stream substrate. - Wide, flat profile makes it possible to improve fish passage by back watering the structure.	- Wide bottom area of culvert enables passage of high flows while minimizing increases in flow depth. - Large waterway opening for low clearance installations.
	- Avoid use in fish bearing streams of incorporate appropriate design modifications. - Represents a compromise between pipe arch and round culvert cross sections. - Stream substrate not easily retained in culvert.	- Squat profile useful in low fill situations. - Shape results in deeper water depth than pipe arch, but does not offer as broad a bottom area.
	- Allow for fish passage during wider range of flows than single culvert.	- Same hydraulic properties as type of single culvert used (Round, Box, etc.).
	- Avoid use where fish passage is important. - Inncorporate approved design modification to permit fish passage. - High turbulence and other hydraulic properties greatly discourage fish passage. - Baffles are difficult to install.	- Generally constricts stream width and creates high flow velocities with increased chance of scour. - Concentrates water during low flows.
	- If properly designed and installed, it does limit fish passage. - Ensure proper decking to avoid introduction of sediment and debris into the stream. - Maintains natural stream bed and gradient.	- Exercise care not to restrict stream width. - Normally only used as a temporary facility

Figure 14.2 Fisheries and hydraulic concerns for various culvert designs (adapted from Dane, 1978a and Wightman, 1976).

Design and Installation Guidelines


b
0.495b
0.125b
0.380b
1.12b*
30°
90°
flow
b
D
0.096D

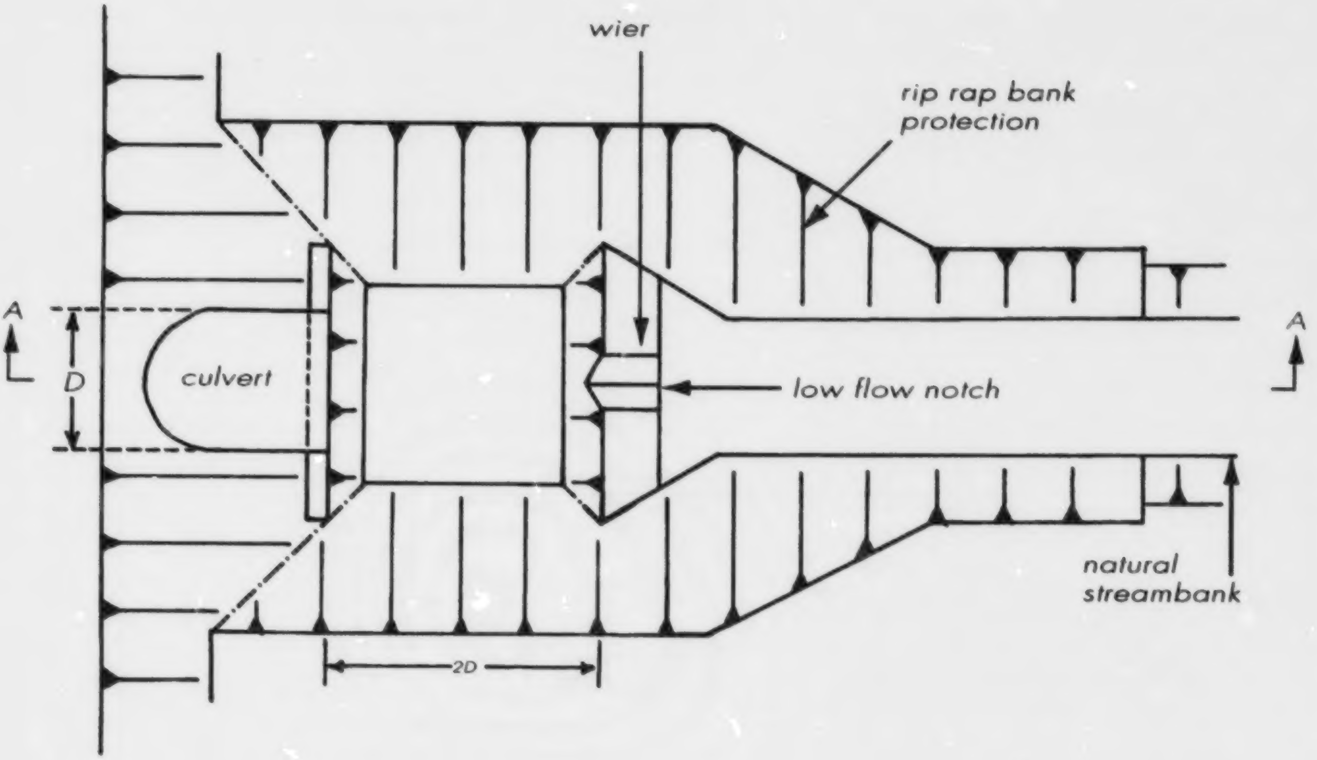
Plan

Note:
1. Minimum b=1.5m
2. Minimum baffle height=0.31m
* For pipe arch, b=rise of pipe for this dimension only.

Cross-Section

Figure 14.3 Design criteria for offset baffles.

Design and Installation Guidelines


wier
rip rap bank protection
A
D
culvert
low flow notch
A
natural streambank
2D

Plan View

Section A-A

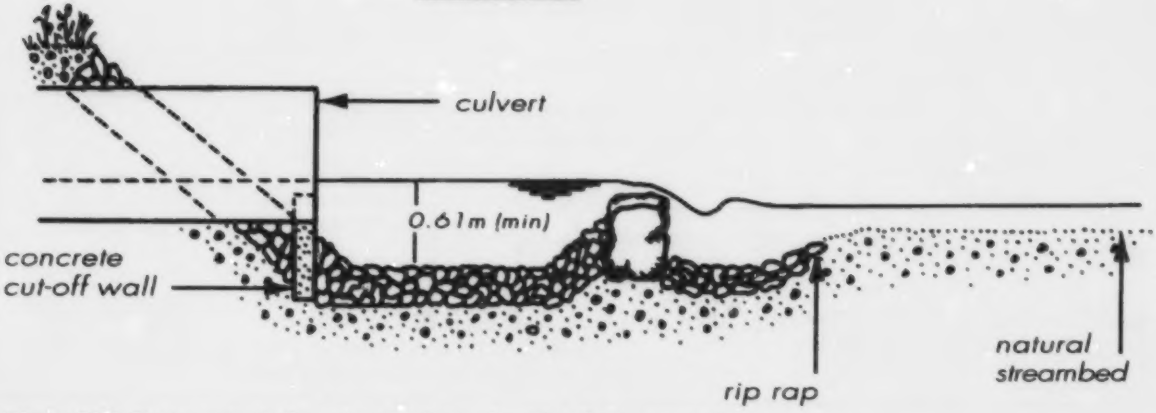

culvert
0.61m (min)
concrete cut-off wall
rip rap
natural streambed

Figure 14.4 Design criteria for culvert outlet pools with tailwater control.

Design and Installation Guidelines

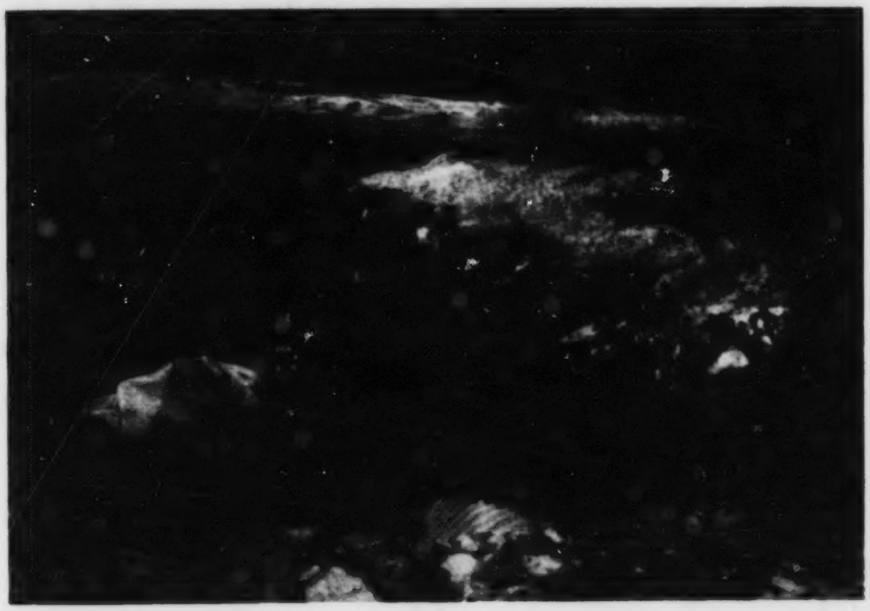


Figure 14.5 *An outlet pool and a series of low head weirs below a culvert. These weirs are made of wood and are notched to concentrate low flows.*

Maintenance

When properly designed and installed, baffles should be maintenance-free for many decades. Although they will accumulate some sediment, the effectiveness of the baffles should not be appreciably diminished (Figure 14.6). Wooden baffles may eventually require replacement.

Outlet pools and control weirs should be checked periodically to ensure that the structures are stable during high flows and functional during low flows.

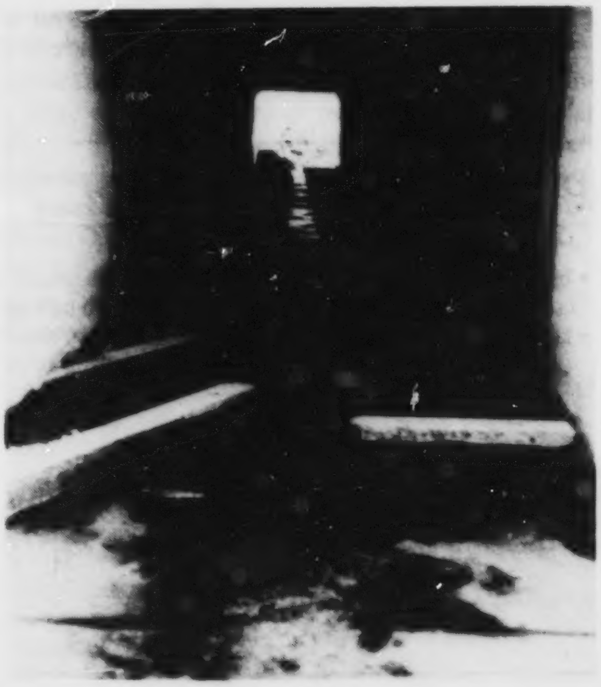


Figure 14.6 *"Offset" baffles in a concrete box culvert.*

Factors Influencing Cost

Baffles

- installation is labour intensive
- the number and size of baffles increase as the length and width of the culvert increase
- culvert shape affects the complexity of design and construction; (e.g. fitting baffles to round or elliptical culverts requires much more time and effort than fitting baffles to rectangular (box) culverts)
- equipment and labour requirements vary according to the material used in the culvert and the baffles; (e.g. welding equipment is required for metal culverts, concrete drills and fasteners for concrete culverts, and cement mixers for concrete baffles)
- electrical power may be required; if a permanent electrical source is not available at the site, a portable generator will be required

Outlet Pools

- design and construction are labour-intensive
- larger culverts require larger outlet pools, which in turn require more material and time to construct
- multiple control weirs may be required to overcome large drops
- availability of large rocks and rip rap
- heavy machinery may be required

Advantages of Technique(s)

- baffles and/or outlet pools permit unimpaired migration to habitats upstream of previously impassable culverts
- in most cases, it is less expensive to add baffles and/or an outlet pool than to replace an improperly installed culvert
- provision of an outlet pool will also decrease velocities and increase depths in the culvert by backwatering
- sites are usually accessible since most culverts are located at road, highway or railway crossings

Disadvantages of Technique(s)

- baffles reduce the flow capacity of the culvert
- labour intensive
- specialized equipment and tradesmen may be required
- heavy machinery costs

Examples of Use

Culvert Baffles

Hoy Creek, Coquitlam, B.C.: Wooden baffles were installed in a large box culvert under the Barnet Highway. The baffles function very well despite accumulations of bedload and urban debris.

Compensation Creek, Surrey, B.C.: A precast concrete box culvert with offset baffles was installed at 140th Street in 1987. The culvert will aid in conveying water and facilitates unobstructed coho salmon migration.

References

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Saremba, J. and J.S. Mattison. 1984. Environmental Objectives and Procedures for Water Crossings. Ministry of Environment Technical Report 6:85p.

Wightman, J.C. 1974. A brief summary of fish passage problems at culvert installations with special reference to swimming performance. Fish Habitat Improvement Section, Fish and Wildlife Branch. Victoria, B.C.

15 *Fishways*

Introduction

Fishways are widely used to provide passage around or through both natural and man-made migration barriers. While many older man-made obstacles were designed without concern for migrating fish, most modern instream structures such as hydroelectric dams incorporate fishways into their design to provide unimpeded passage for migratory fish.

Fishways are characterized by regularly spaced baffles that control water depth and velocity to provide fish with an easy ascent route. There are many types of fishways that can be differentiated primarily by the design and configuration of the baffle. Most fishways are, however, variations of three basic designs. Weir fishways, vertical slot fishways and Denil fishways are discussed in this chapter.

Application

Before commencing any project involving the construction or installation of fishways, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

Fishway design requires considerable engineering expertise and should be performed by qualified engineers. Construction or installation of fishways should be directly supervised by fishery agency personnel.

Fishways may be installed where obstructions impede or prevent fish migration to historic production areas or to previously unused, but potentially productive, stream habitat. Fishways can be used where obstruction removal is not possible or economically feasible. Inexpensive, temporary fishways and/or headwater stocking programs can be used to assess potential benefits of permanent fishways.

Weir fishways are best suited to streams with minimal fluctuation in water level, such as streams regulated by large lakes or dams. Vertical slot fishways are designed to be functional in streams with widely fluctuating water levels. Denil fishways are designed to overcome steep slopes, and can be used on a temporary basis for project assessment or installed where more expensive fishways cannot be justified.

Design and Installation Guidelines

General

Fishways vary immensely in size, complexity and cost, but are all designed to perform a single function: dissipate the energy of flowing water throughout the fishway so that migrating salmonids can ascend without unnecessary stress or delays.

Although the flume and baffle components vary significantly in design, other design considerations are common to all fishways. The fishway entrance (downstream end) should be located where fish naturally congregate. Fish can be attracted to the entrance by providing a concentration of flow or by directing fish to the entrance with a barrier dam. The fish exit (upstream end) should be located

Design and Installation Guidelines

far enough above the obstruction to prevent fish from being swept back over the obstruction. A debris deflector and/or trash rack should be installed at the exit to keep the fishway clear.

Weir Fishways

The weir fishway, also known as the pool-and-weir fishway, is the oldest and simplest form of fishway. A series of low weirs are installed in a channel at progressively lower elevations from above the obstruction to a point below (Figure 15.1). Water flows from pool to pool over a series of low drops. Migrating salmonids ascend the fishway without difficulty as they are provided with relatively deep pools from which to make low jumps. Fish can rest in any of the pools along the fishway.

Figure 15.1 A simple weir-type fishway. The weir crests have been sloped as an alternative to notches.

Weir fishways have limited application since they are functional only within a narrow range of stream water levels. Consequently, they are generally restricted to use on streams with regulated flows, such as those downstream of large lakes or dams. Two variations of the weir fishway have expanded its applicability. In the first variation, notches are added to the weirs to improve passage at low flows. In the second, (also to improve passage at low flows), orifices are incorporated in the weirs to allow fish to move from pool to pool without jumping over the weirs (Figure 15.2).

Vertical Slot Fishways

The vertical slot fishway was designed specifically for streams characterized by widely fluctuating water levels. Specially-designed baffles are installed vertically so that water levels throughout the fishway self-adjust to variations in headwater and tailwater elevations. The vertical slot fishway will function properly provided the rise in headwater and tailwater are in unison. Special design considerations must be incorporated if this is not the case. Energy is dissipated when the jet of water that flows through the narrow vertical slot of one baffle is turned back against itself by the upstream face of the next downstream baffle (Figure 15.3). Migrating fish proceed through the fishway by darting through the narrow slots. The pools between the baffles provide resting areas. Small fishways employ a single slot design, large fishways use a double slot design.

Design and Installation Guidelines

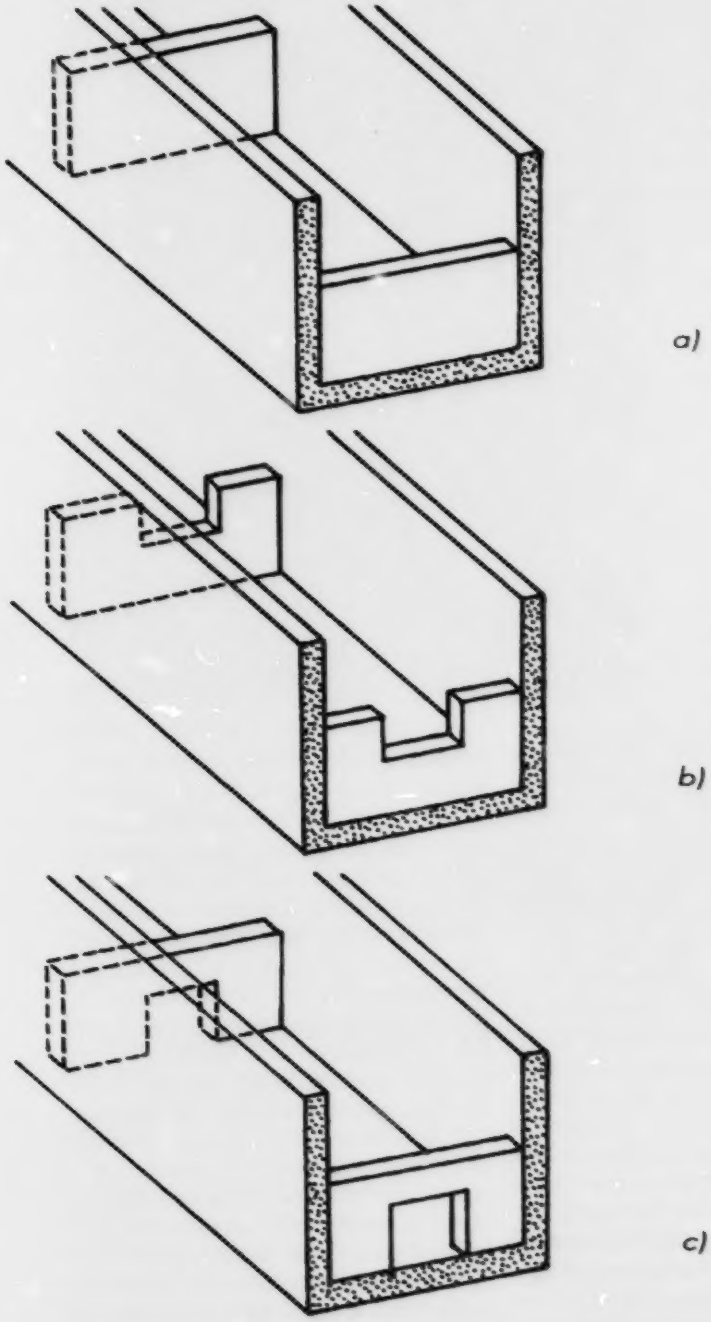

Figure 15.2 Weir fishway designs. Simple weir fishway (a), fishway with notches (b), and fishway with orifices (c). (Adapted from Bell, 1986).

Design and Installation Guidelines

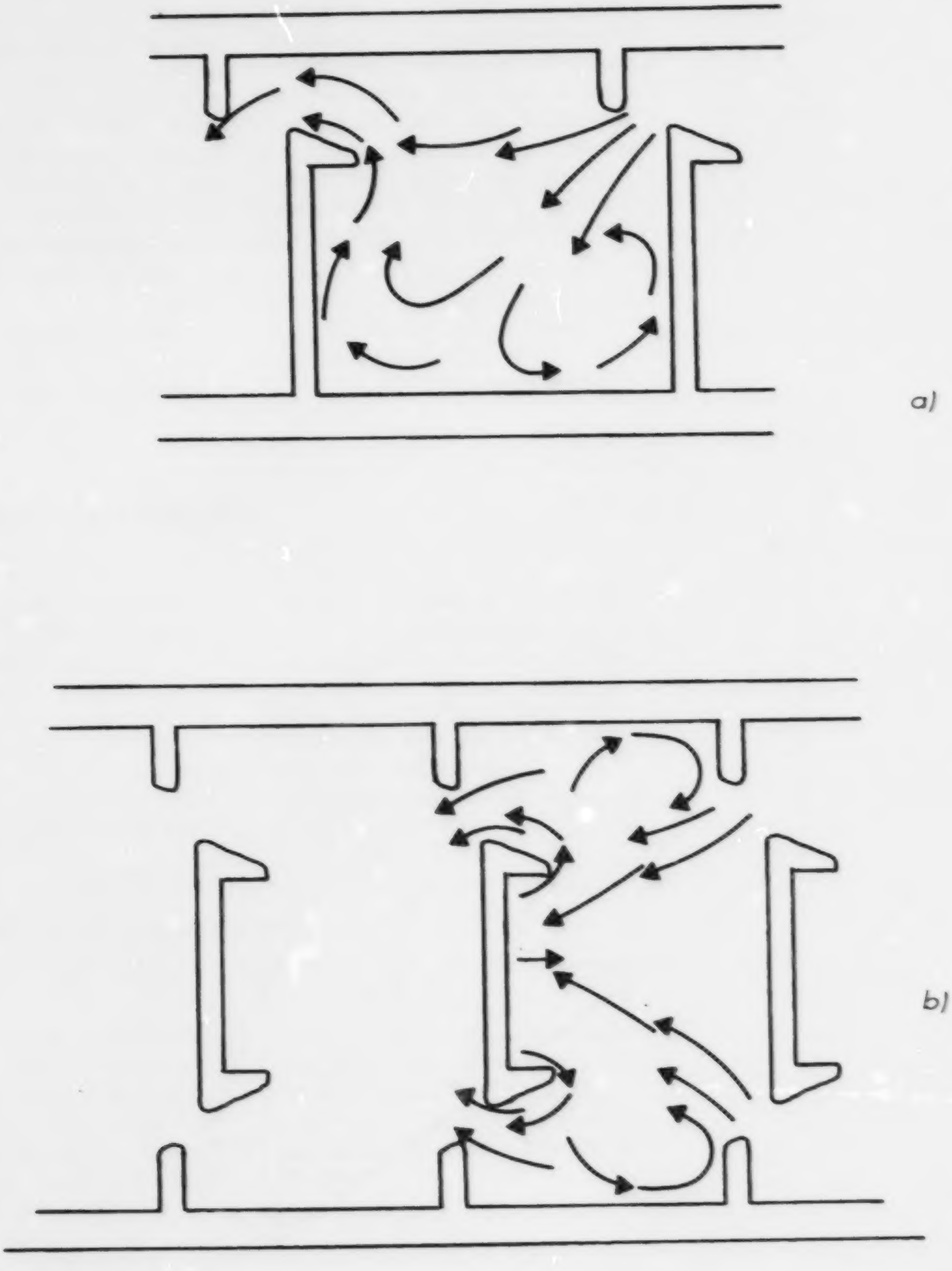

Figure 15.3 Vertical slot fishway designs. Single slot fishway (a) and double slot fishway (b). (Adapted from Clay, 1961).

Design and Installation Guidelines

Denil Fishways

The Denil fishway employs vanes attached to the side and bottom surfaces of a flume to turn the flow of water back against itself (Figure 15.4). This produces a turbulent outer layer with an inner zone of relatively slow flowing water in which fish ascend. There are no resting areas within the fishway itself. Resting pools may be required between long sections of fishways. Denil fishways tend to be quite small, but can be installed at slopes exceeding those appropriate for weir or vertical slot fishways. The Alaskan Steeppass, a variation of the Denil fishway, was designed specifically for use in steep slope situations. Due to the complex arrangement of vanes in Denil fishways, they are usually constructed of aluminum and installed as prefabricated units.

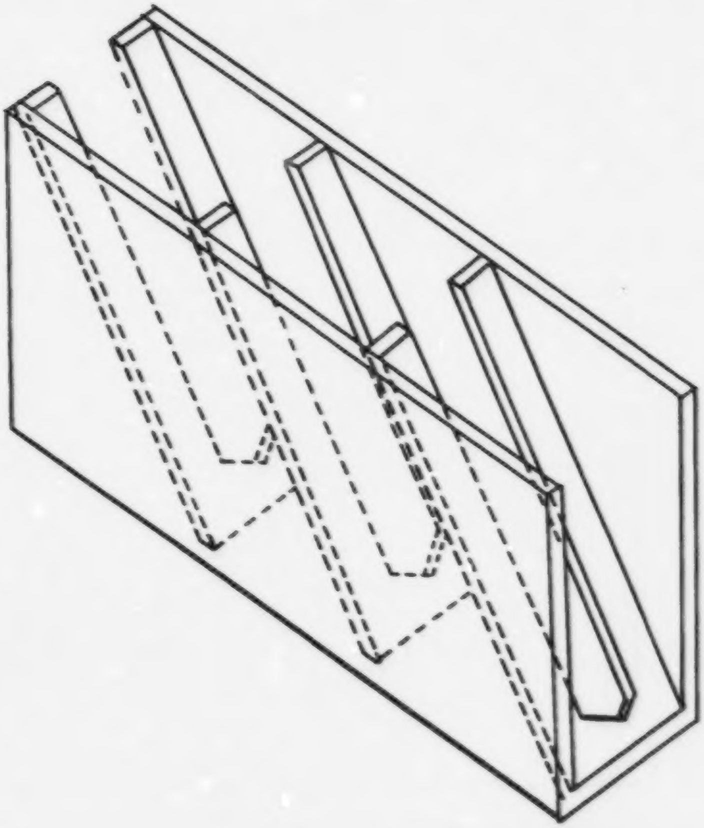

***Figure 15.4** Denil fishway design. (Adapted from Bell, 1986).*

Maintenance

Fishways should be inspected at least once each year, especially at the start of the migration period, to ensure that they are functioning properly. Structural damage such as eroded concrete or bent debris deflectors should be attended to. Accumulations of debris or bedload in the fishway or at the entrance or exit should be removed.

Factors Influencing Cost

- type of fishway required
- type of obstruction and other site conditions
- anticipated life expectancy of the structure
- magnitude and timing of runs (affects dimensions)
- site accessibility
- cost and availability of materials
- size and number of associated features (debris deflectors, barrier dams, auxiliary water supply, etc.)
- amount of site preparation work required

Advantages of Technique(s)

- fishways permit passage past obstructions that otherwise prohibit passage or cause migration delays
- fishways can be used to introduce salmonids into stream areas previously unused by anadromous species
- fishways can be designed to selectively permit passage of only desired salmonid species while blocking the migration of undesired fish species
- it may be less expensive to construct a fishway than to remove or alter an obstruction
- temporary fishways can be installed to assess the potential of a more expensive, permanent fishway
- use of the fishway by salmonids can easily be monitored

Disadvantages of Technique(s)

- major fishways and fishways on rivers with large water level fluctuations require detailed hydraulic and engineering studies in order to ensure that the proposed works will not alter the existing hydraulic regime of the stream
- fishway construction is relatively expensive and labour intensive
- introduction of a species into a previously inaccessible stream area may cause undesirable impacts on existing resident fish populations
- fishways must be kept free of debris and bedload in order to function as designed

Examples of Use

Weir Fishways

Millstone River, Vancouver Island, B.C.: A simple weir fishway was constructed using volunteer labour. Pools and steps were formed in the solid rock streambed by drilling and blasting.

Puntledge River, Vancouver Island, B.C.: A modified weir fishway was constructed at Nib Falls. The basic channel was excavated in solid rock. Concrete baffles with vertical slots were installed.

Brooklyn Creek, Vancouver Island, B.C.: A weir fishway was constructed using concrete and rock-filled gabions. Access has been provided to about 1 kilometre of habitat that was alienated by an improperly installed culvert.

Vertical Slot Fishways

Fraser River, Hell's Gate, B.C.: A double vertical slot fishway was developed by the International Pacific Salmon Fisheries Commission to alleviate the fish passage problem that resulted from railroad construction. Other vertical slot fishways have been installed and proven successful on the Kakweiken River (Thompson Sound), Seton Creek (near Lillooet) and the Meziadin River (Nass River system).

Denil Fishways

Kakweiken River, Thompson Sound, B.C.: A Denil (steeppass) fishway was installed as a temporary passage structure to assess the use of spawning habitat above an obstruction. Subsequent utilization of the stream above the obstruction led to the construction of a permanent vertical slot fishway.

Hastings Creek, North Vancouver, B.C.: A Denil (steeppass) fishway was installed on this small tributary to Lynn Creek. It was installed to provide passage at a culvert obstruction.

Salmon River, Langley, B.C.: A Denil (steeppass) fishway was constructed to bypass a bridge obstruction (Figure 15.5).

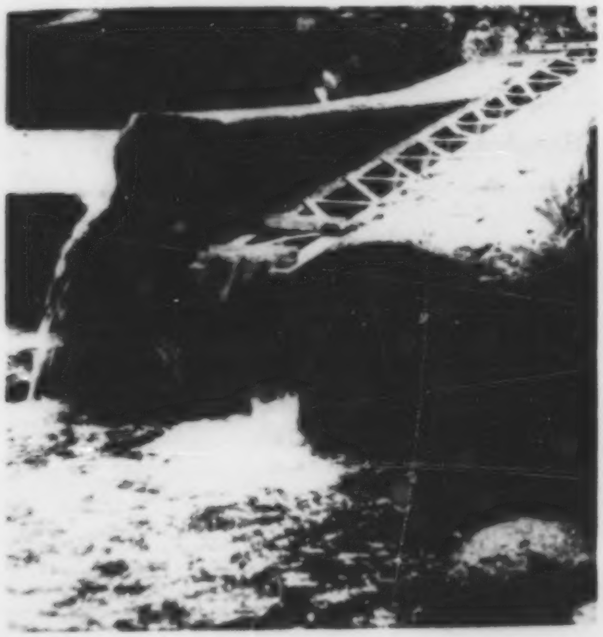

***Figure 15.5** This Denil fishway provides passage for coho salmon and steelhead trout on the Salmon River in Langley, B.C.*

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Reeves, G.H and T.D. Roelofs. 1982. 12. Rehabilitating and enhancing stream habitat: Part 2. Field applications. Influence of Forest and Rangeland Management on Anadro-

16 *Fish Screens*

Introduction

Much of the water that is used for domestic, industrial and agricultural purposes is withdrawn directly from streams and lakes that support salmonid populations. Many intakes are equipped with electric submersible impeller pumps that cause high fish mortality during operation.

Fish screens are used almost universally to protect fish from entering water intakes or diversion channels at water withdrawal points. Screening systems vary widely in size and complexity. For the purpose of this document, commonly used screen systems have been divided into two groups: fixed screens and moving screens.

Application

Before installing or constructing any fish screening structure, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

The Fisheries Act specifies that fish screens must be installed at the entrance to every intake, ditch, channel or canal that conveys water from fish-bearing streams or lakes. While individual cases are dealt with on a discretionary basis, this rule generally applies to all waters inhabited by salmonids.

Small diversion structures and intake pipes can be fitted with simple fish screens by the water user, however, screening systems generally become increasingly elaborate as the amount of water to be withdrawn increases. Engineers and qualified contractors should be retained to design and construct larger fish screens.

Design and Installation Guidelines

General

Some design considerations are common to almost all fish screening systems. Basic features include screen material of appropriate mesh size, debris removal capabilities and fish bypass routes.

Mesh size is selected according to the size and species of fish that the screen is to exclude. For salmonids, spacings between the mesh strands should not exceed 2.5 mm (0.10 inch). This size has been shown to effectively prevent passage of emergent pink salmon fry of about 25 mm (1 inch) length. Screens with finer mesh openings may experience fouling problems from filamentous algae. Metal surfaces with slots or holes can be used as a substitute for mesh material.

All screens must be designed to either avoid accumulation of debris or be self-cleaning. Otherwise, screens in streams that carry high debris loads will require frequent cleaning to function properly. Trash racks should be installed upstream of the point of withdrawal to prevent damage by large debris.

All screening systems should be designed to prevent impingement of small fish against the screen. If fish enter a diversion channel that leads to an intake,

Design and Installation Guidelines

they may congregate upstream of the withdrawal point, mistaking the intake structure as a migration avenue. They often become fatigued or stranded by low water in the channel.

A bypass channel should be constructed to provide a passage route around the screen and back to the main stream channel. This reduces the incidence of fish being trapped against the screen and prevents delays in downstream migration. To avoid impingement, the water velocity through the screen should not exceed 0.03 m/sec for fixed screens and 0.12 m/sec for moving screens. The intake to a fish bypass channel should be designed to provide a transverse velocity (parallel to the screen face) which leads fish to the bypass or past the screen before they become fatigued.

Fixed Screens

The simplest fish screen is a flat, framed section of mesh material installed vertically in a channel. The sections of screen should be removable to permit cleaning. This form of screen device is applicable where the amount of water being diverted is quite small (less than 0.028 m^3/sec or 1 cfs).

A more complex version of a fixed screen system is the horizontal-vertical screen (Figure 16.1) that is commonly used in diversion channels. Water flows through screens on the bottom and end-wall surfaces of the screening structure while sufficient flow is diverted to a bypass channel.

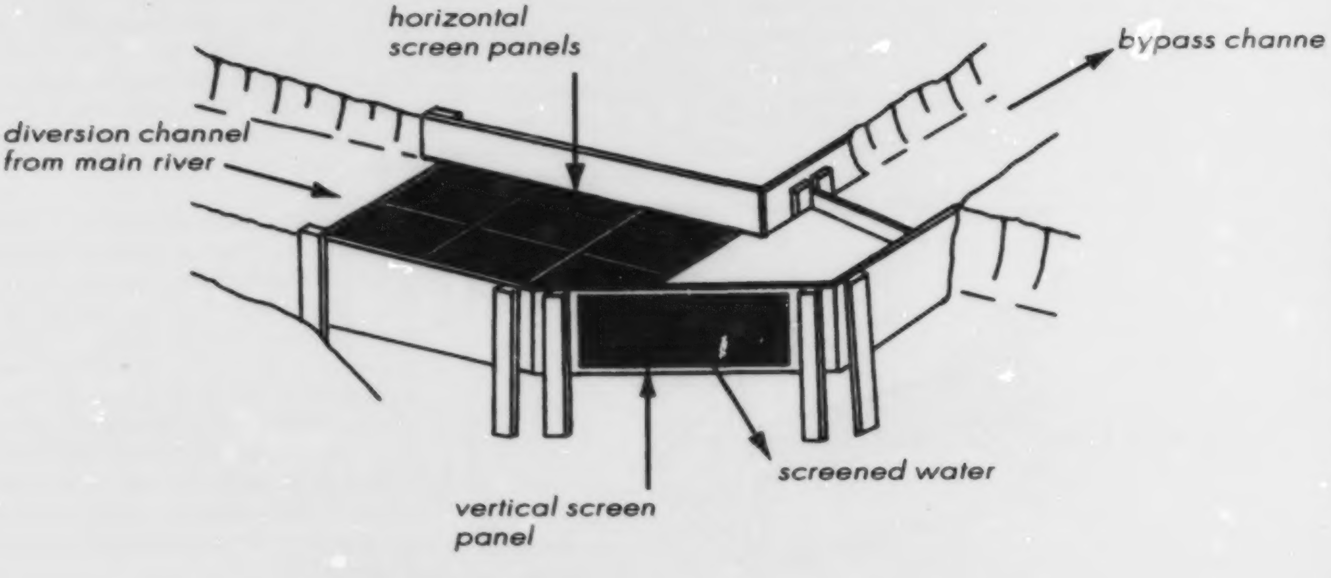


Figure 16.1 Horizontal-vertical screen for use in a diversion channel. Fish and debris return to the main stream channel via the bypass channel.

Design and Installation Guidelines

Where water is withdrawn directly from a large stream a series of fixed vertical screens, also known as an infiltration gallery, can be used. This type of structure is installed parallel to the direction of flow in the stream, at the outside of a curve. The flow of water past the screen minimizes debris accumulation and keeps juvenile migrants on course. Water passes from the stream to the diversion channel through a slotted metal surface. An inclined weir is usually installed across the stream channel to concentrate low flows towards the screen.

The intake pipe of pumps used to extract water form lakes or streams should also be screened. Commercially manufactured well screens (Figure 16.2) are ideal for this purpose. A well screen is a cylinder of wrapped stainless steel strips designed for use at the bottom of a well. When installed in a stream, water enters the pipe through the slots between the metal strips, which are too closely spaced to allow sediment or juvenile fish to enter.

Simple, home-made screens can be fashioned from readily available materials (Figure 16.3). An old metal drum can be converted to a fish screen by cutting out panels from its side and replacing them with wire mesh. A frame made of wood or metal can likewise be covered with wire mesh to form a screen. A section of pipe can be perforated by drilling holes or cutting slots and sealing with screen. One end is left open for attachment to the conveyance pipe. The screen can either be attached to a weighted frame and lowered to stream/lake bottom or suspended below a floating raft. In the latter case, flexible hose should be used to connect the intake screen to the pipe to allow for fluctuations in water level.

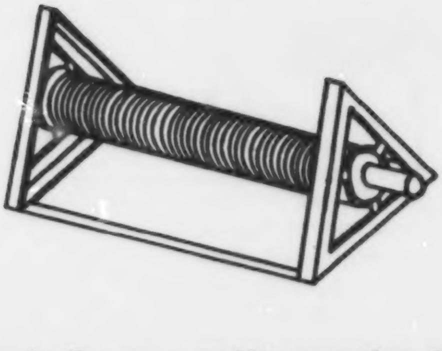


Figure 16.2 Stainless steel well screen mounted in a support frame for installation on a streambed or a lake bottom.

Moving Screens

Maintenance is reduced by designing screening systems that are self-cleaning. Moving screens are those with panels or other components that move in order to keep the screen free of debris. Moving parts can be motor-driven or powered by flowing water.

A fish screen commonly used in industrial applications is the vertical travelling screen (Figure 16.4). It is composed primarily of a series of screen panels connected together in belt-like configuration. The screens are rotated around large sprockets by an electric motor. The upstream face of the screen system moves upwards, lifting debris off the screens and onto horizontal debris collectors. Debris is washed off the screen and collectors by water sprayers.

Revolving drum screens are widely used in irrigation ditches. A cylinder-shaped screen is installed perpendicular to the flow, with no more than three-quarters of the drum below the water level. All water passes through one side of the drum and out the other. The drum is rotated so that debris collects on the upstream side of the drum, then is washed off of the drum as it rotates to the opposite side. The drum can be rotated either by an electric motor or by a water-driven paddlewheel system (Figure 16.5).

Design and Installation Guidelines

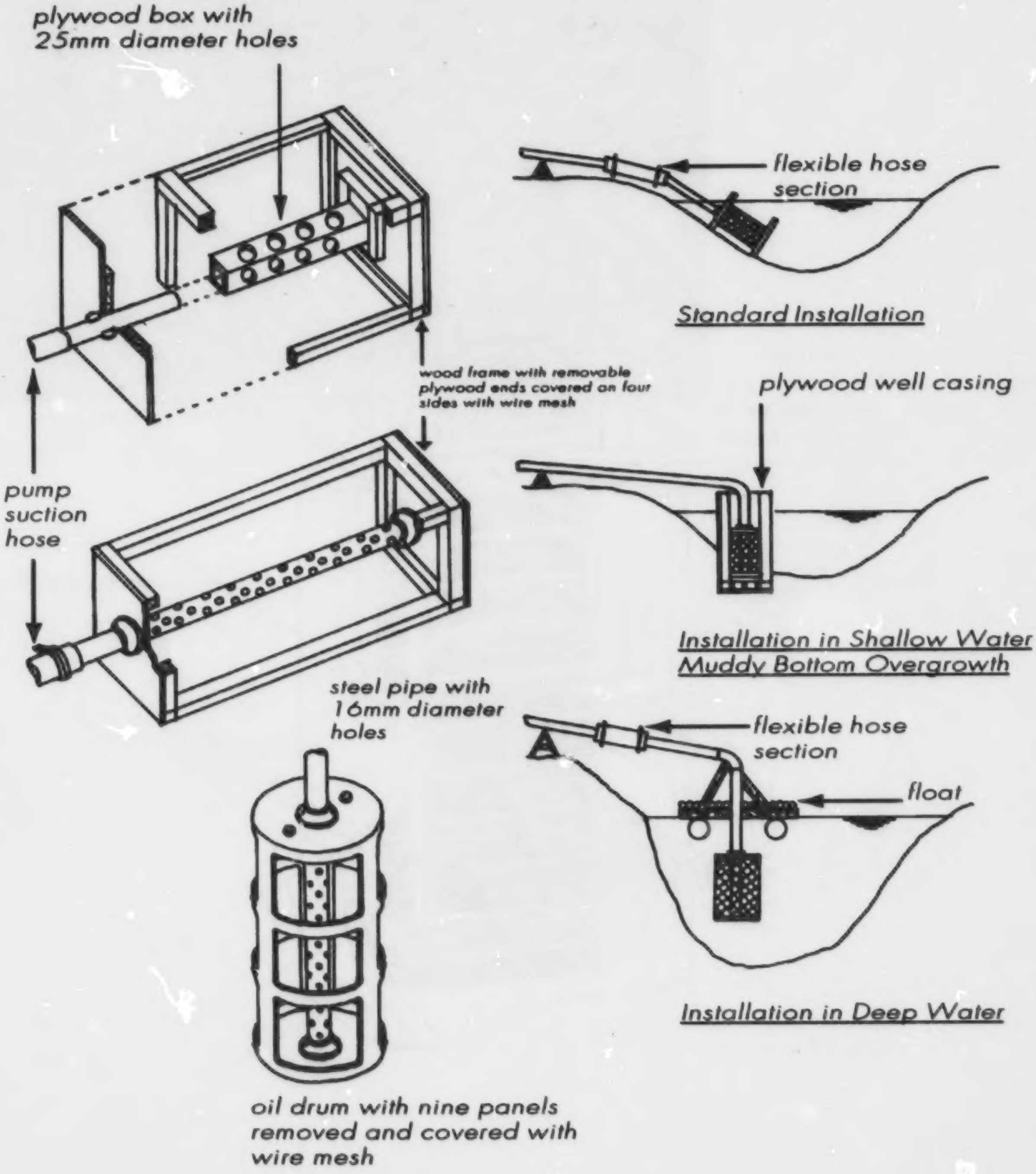

plywood box with 25mm diameter holes
wood frame with removable plywood ends covered on four sides with wire mesh
pump suction hose
steel pipe with 16mm diameter holes
oil drum with nine panels removed and covered with wire mesh
flexible hose section
Standard Installation
plywood well casing
Installation in Shallow Water Muddy Bottom Overgrowth
flexible hose section
float
Installation in Deep Water

Figure 16.3 Simple screens for use on low capacity, pumped intakes.

Design and Installation Guidelines

Another self-cleaning system is the Finnigan screen (Figures 16.6 and 16.7). Water is screened by a horizontally-mounted perforated metal plate. A paddlewheel is installed horizontally over the screening surface and is rotated by the flow of water entering the screen. Brushes attached to the arms of the paddlewheel clean debris off of the screen. The debris is then washed away through the fish bypass channel.

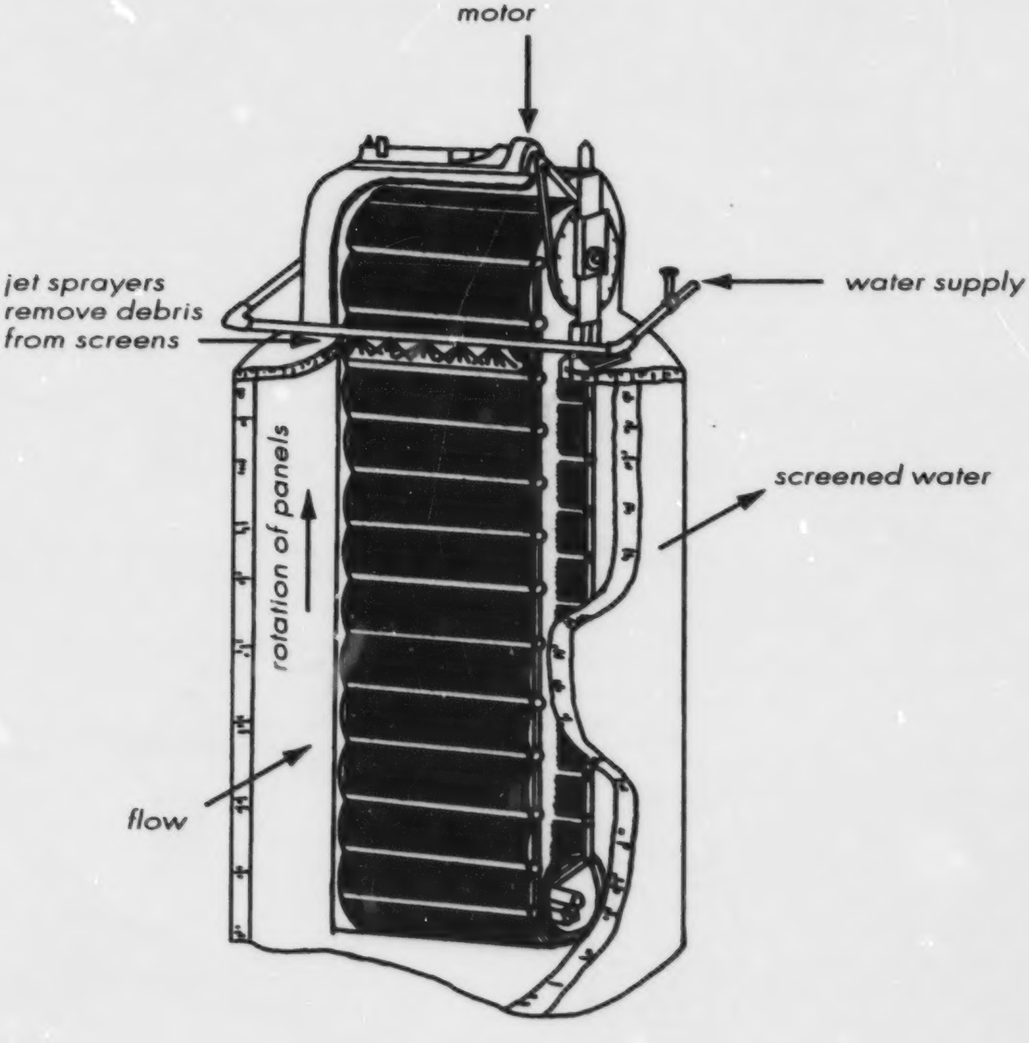
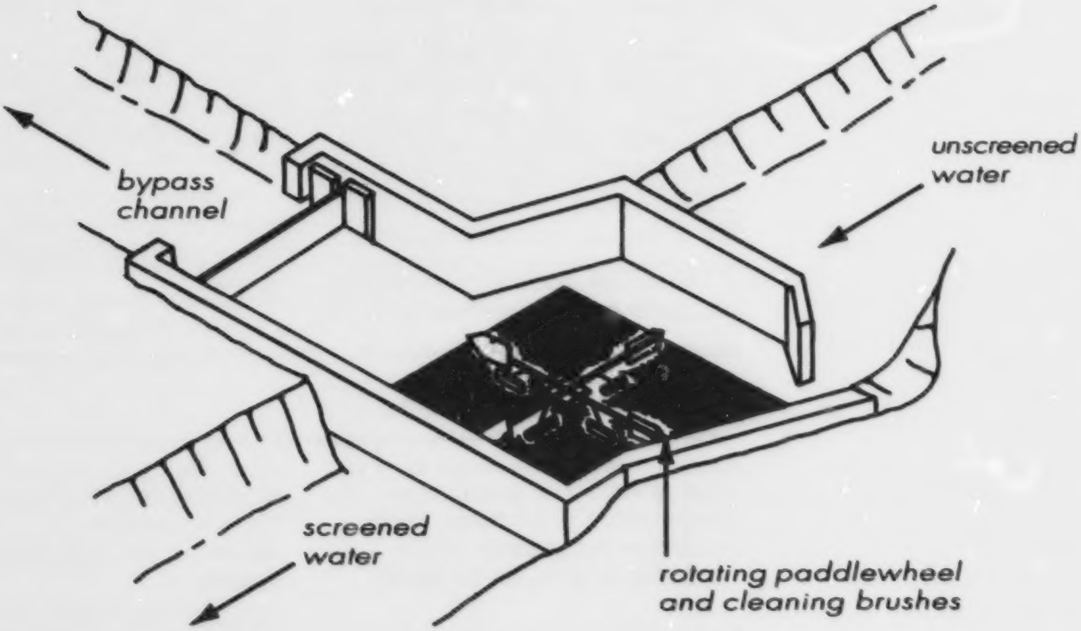

motor
jet sprayers remove debris from screens
water supply
rotation of panels
screened water
flow

Figure 16.4 Basic design components of a vertical travelling screen.

Design and Installation Guidelines

Figure 16.5 A revolving drum screen installed on an irrigation diversion channel.



bypass channel
unscreened water
screened water
rotating paddlewheel and cleaning brushes

Figure 16.6 A Finnigan screen. Water passes downwards through the screen into the diversion channel. Fish and debris return to the main channel via the bypass channel. An adjustable weir maintains the water level in the screen.

Design and Installation Guidelines

Figure 16.7 A Finnigan screen during construction.

Maintenance

Debris removal and screen cleaning are the most frequent maintenance requirements of fish screening systems. Large debris should be removed from trash racks and screens should be washed to remove debris or algae that clog screen openings.

All screens should be inspected regularly, particularly during periods of juvenile migration. There should be no gaps in or around the screen that would allow fish to proceed further along a diversion channel or into an intake pipe.

Bypasses and escape routes should be clear and flowing properly. All moving parts should be maintained in good working order.

Factors Influencing Cost

- type of withdrawal system; pipes require only a simple intake screen while diversion channels require screening systems with fish bypass routes
- volume of water being diverted. In general, the size of the screen required increases as the amount of water being diverted increases; costs are greater for larger and more complex screen systems
- debris load of the stream or diversion channel; screens in streams with high debris loads require more frequent cleaning or use of self-cleaning systems
- type of screen system used; moving screens tend to be more costly to build and require more maintenance
- where electrical power is used the long term cost of the electricity must be taken into account; if the screen is located in a remote location, consider the distance to the nearest source of electricity

Advantages of Technique(s)

- fish screens that are properly installed and operating will permit water to be withdrawn with negligible losses of fish
- bypass channels will return migrating fish to the main channel of the stream with minimal delays
- self-cleaning systems can be used in streams with high debris loads to minimize cleaning requirements

Disadvantages of Technique(s)

- screen systems for most industrial or agricultural purposes tend to be quite elaborate and costly
- maintenance schedules must be flexible to accommodate seasonal fluctuations in flows and debris load; maintenance requirements are often underestimated

Examples of Use

Fixed Screens

Deadman River, B.C.: Horizontal-vertical screens are in operation at several locations along the middle reaches of the river, where water is withdrawn for irrigation.

B.C. Hatcheries: Fixed vertical screens are used on the water intake systems at many salmonid hatcheries, including those at Chilliwack River, Big Qualicum River, Little Qualicum River and Kitimat.

Thompson River, near Martel, B.C.: A fixed screen is used at the Lornex Mine water intake.

Moving Screens

B.C. Hatcheries: Vertical travelling screens are used on the water intake systems at the Puntledge River and Nitinat River hatcheries.

Nicola River, B.C.: Revolving drum and Finnigan screens are used at several locations where irrigation water is withdrawn. A revolving drum screen is located on the Nicola River at the Gavelin Ranch, 11 kilometres downstream of Merritt. Finnigan screens are in use on the Nicola River at the Chutter Ranch (immediately downstream of Nicola Lake) and at the Neale ranch, 6 kilometres downstream of Merritt.

Coldwater River, B.C.: Finnigan screens are located on the Coldwater River at the Strand Ranch, 11 kilometres upstream of Merritt and at the Coldwater Ranch, 24 kilometres upstream of Merritt.

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17 *Streamflow Control*

Introduction

Streamflow affects velocities, depths, substrates, space, cover, temperature and water quality. Although salmonids are tolerant of relatively wide variations in streamflow, extreme high and low flows can impose serious limitations on their production.

High flows increase egg mortality by scouring incubation substrates, and introducing fine sediments to these substrates from actively eroding upstream habitats. Winter low flows can cause dewatering of redds and freeze eggs into the gravel.

Juvenile mortality is increased by high flows that flush rearing salmonids out of refuge habitats. Low flows during the summer months can severely restrict rearing space and available food, and contribute to high water temperatures and correspondingly lethal low dissolved oxygen levels. Lack of sufficient depth over riffles can also prevent migration of adult salmonids.

Streamflow control may be achieved by storing water during periods of high runoff for release during periods of low runoff. Water may be stored in an existing lake or a man-made impoundment and regulated to varying degrees, depending on the inflow to the impoundment, the amount of available storage and the characteristics of the flow control structures. Water temperature can also be regulated to some extent by withdrawing water from various depths within the impoundment. Streamflow control projects that benefit fish range in complexity from the installation of plastic pipes to siphon water out of beaver ponds to the construction of large, multi-purpose dams.

Application

This chapter deals exclusively with the control of surface water. Interception of groundwater flow to augment surface flow is discussed in Chapter 11.

Before commencing any streamflow control project, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

Salmonid populations in small coastal streams susceptible to floods and/or droughts are most likely to benefit from streamflow control.

Most streamflow control projects are undertaken by resource agencies due to the high costs and the need for considerable technical expertise (engineers, hydrologists and biologists). Some small scale projects may be undertaken by public involvement groups under the direction of resource agencies.

Storage is an essential element of a streamflow control project. Storage can be created either by increasing the storage capacity of an existing lake or reservoir, or by constructing a new reservoir. The lake/reservoir must be situated upstream of the section of stream that is to be improved. Storage impoundments should not be created at the expense of important existing fish or wildlife habitat. The proposed water level fluctuations must be acceptable to major user groups and owners of foreshore lands.

Design and Installation Guidelines

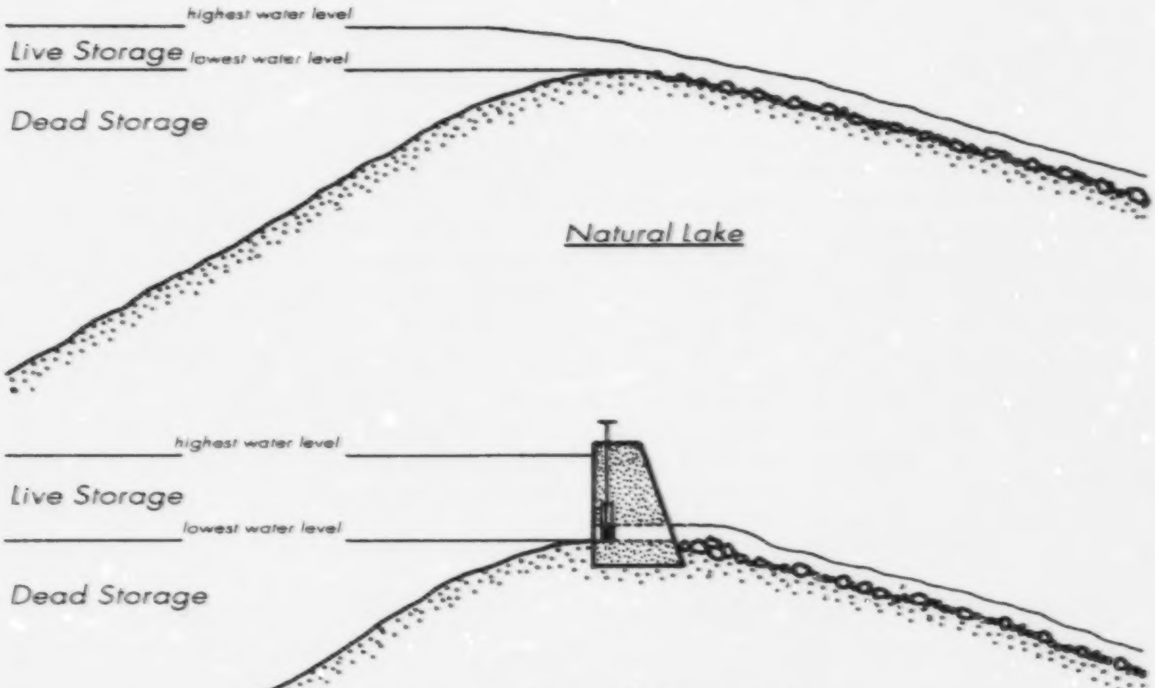

highest water level
Live Storage
lowest water level
Dead Storage
Natural Lake
highest water level
Live Storage
lowest water level
Dead Storage
Lake with Dam and Sluice Gate
highest water level
Live Storage
lowest water level
Dead Storage
Lake with Low Level Discharge Pipe

Figure 17.1 *Means of increasing live storage of a lake or impoundment.*

Design and Installation Guidelines

The most common approach to flow control is to increase the live storage capacity of a lake (Figure 17.1). Live storage is the volume of water between the lowest and highest water elevations. There are two means of increasing the live storage of a lake or impoundment: first, a dam can be constructed to raise the maximum water level elevation; and second, water release structures can be installed below the natural lake outlet to lower the minimum water level elevation.

If the water level in a lake is maintained at its minimum level, a flood flow passing through the impoundment can be reduced by an amount equivalent to the storage capacity of the impoundment. Impoundments operated for flood control purposes require large storage capacities relative to the storage capacities required to augment low flows. Further discussion will focus on low flow augmentation projects.

Storage capacity is expressed as volume (impoundment area multiplied by storage depth). The flow that can be produced from this storage depends on the length of time over which the water will be released. The relationship between storage and discharge is:

no. of m^3/sec-days =
lake area (ha) x depth (m) x 0.116

where 1 m^3/sec-day represents a flow of 1 m^3/sec for 1 day or any equivalent flow (e.g. 0.1 m^3/sec for 10 days). For example, increasing the storage depth on a 26 hectare lake by 2 metres would permit a flow of 0.1 m^3/sec for 60 days.

A sluice gate or control valve (Figure 17.2) can be used to regulate the release of water from an impoundment. The sluice gate is often incorporated into the dam structure, however, it may be independent. Trash racks should also be incorporated into all water release structures to prevent organic debris from blocking flow.

All dams should be designed to allow unobstructed fish passage between the lake and the stream below. A fishway is generally required.

A simple flow augmentation project can be undertaken utilizing the water stored

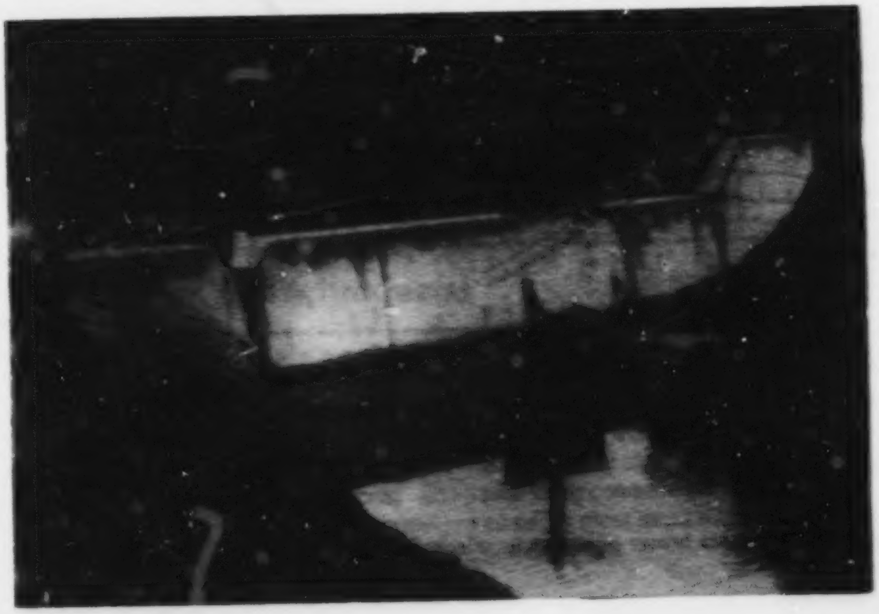
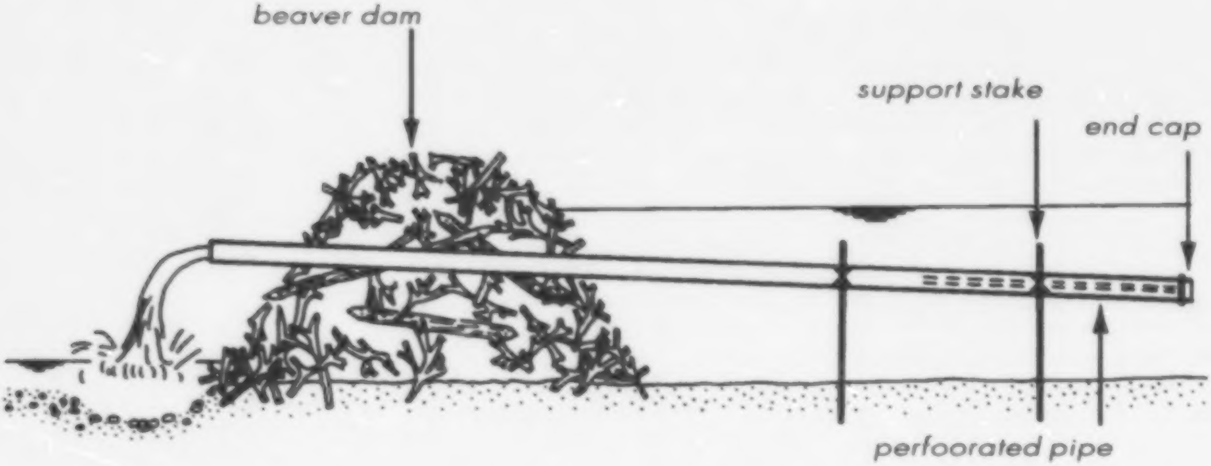
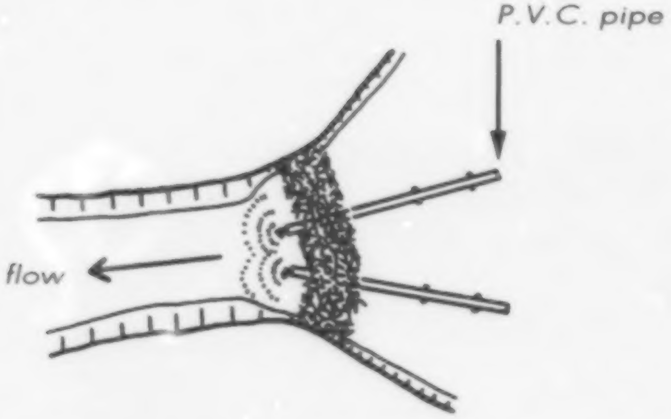


Figure 17.3 *A small flow control dam with a manually operated sluice gate.*

Design and Installation Guidelines


beaver dam
support stake
end cap
perfoorated pipe

Cross-Section Through Beaver Dam


P.V.C. pipe
flow

Plan View

Figure 17.3 To supplement summer low flows, water trapped in beaver dams can be released through a pipe with holes or slots cut into it. The pipe will not be detected by beavers.

Design and Installation Guidelines

in beaver ponds (Figure 17.3). Plastic pipes are used to discharge water through or over an existing beaver dam into the outlet stream. Storage capacity and potential release flows are calculated as before. In this case, live storage is the volume of water between the elevations of the crest of the dam and the outlet pipe. Water enters the pipe through small holes or slots cut into the upstream end of the pipe. If the impoundment is actively maintained by beavers, they will be unsuccessful in their attempts to stop the flow from the downstream end of the pipe as they will be unable to locate the source of the leak.

Maintenance

Most small scale water control structures employ manually operated sluice gates or similar water release mechanisms. The facility must be visited regularly to adjust the rate of release from the impoundment. During these visits all structures should be inspected. The primary maintenance role will be the removal of debris accumulated in or near the water intakes or dam spillways.

Factors Influencing Cost

- scale of project: small projects can be undertaken using readily available materials and volunteer labour; large projects will require complex equipment, detailed technical studies and qualified construction contractors
- topography affects the dimensions of dams: a dam built in a narrow, steep-sided valley will be smaller than a dam built on a wide, flat valley
- amount of storage required: this will be a function of the height of the dam and the depth of water release intakes
- lake area and flow regime of inlet streams: lake area is a primary factor in establishing the height of the dam; the amount of water entering the impoundment is a factor in design of the dam spillway and the capacity of water release structures
- land acquisition: it may be necessary to purchase or secure long term leases on foreshore lands adjacent to lakes where water levels will be increased significantly

Advantages of Technique(s)

- water control projects can produce significant increases in stream productivity where extreme high and/or low flows occur regularly
- during summer drought conditions, the relatively cool water released from a lake or reservoir provides some relief from high water temperatures; streamflow control projects can incorporate structures that allow water to be drawn from various levels of the lake, thereby allowing water temperature to be controlled
- costs for most small scale projects are generally low

Disadvantages of Technique(s)

- flood protection can only be achieved with relatively large storage capacity impoundments
- water levels in project impoundments fluctuate quite widely; impacts may include flooding of lakeshore areas, loss of terrestrial and/or aquatic habitat and diminished aesthetic values
- costs for medium and large scale projects can be extremely high
- fishways or other passage facilities may be required at some structures; potential impacts on migration must be assessed
- regular inspections of facilities are required for maintenance and for monitoring and adjustment of flow rates

Examples of Use

Matheson Lake, Vancouver Island, B.C.: A small dam (1 metre high) was constructed with hand-mixed concrete and boulders to impound water in this small lake. A 10 cm pipe through the base of the dam allows water to be discharged to the stream during summer low flows. An adjustable plate over the end of the pipe is used to regulate the amount of water released.

Elk Creek, Chilliwack, B.C.: The Municipality of Chilliwack and the Department of Fisheries and Oceans cooperated to redesign the intake from the Elk Creek reservoir in order to provide a minimum flow for fisheries. A notched, low level weir is set below the elevation of the intake which permits water to be diverted into the creek during low flow periods.

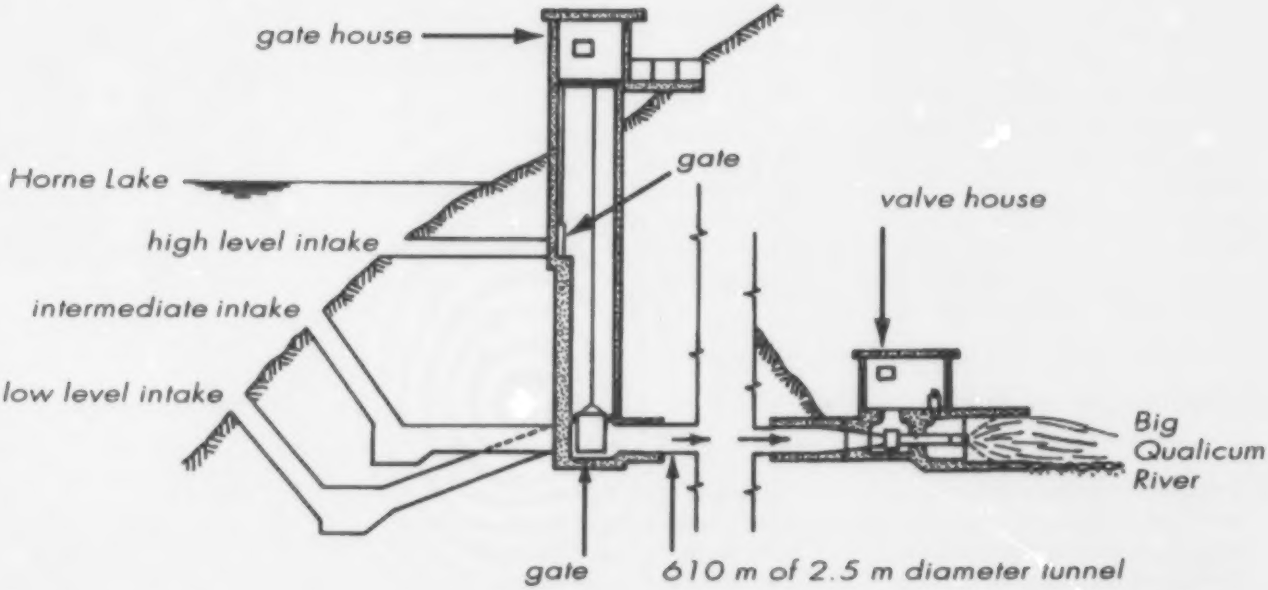


Figure 17.4 Control structures at Horne Lake. Discharge to the Big Qualicum River is regulated at the valve house. Temperature is regulated by mixing water form three different water intakes (adapted from Kerr Wood Leidal and Associates Ltd. and D. B. Lister and Associates Ltd., 1980).

Examples of Use

Weaver Lake, B.C.: During low flows in the fall, water can be withdrawn from below the outlet elevation and released to the Weaver Creek to ensure adequate flow is available for operation of the Weaver Creek spawning channel. The B.C. Fish and Wildlife Branch installed a small concrete fishway at the outlet of the lake.

Horne Lake, Vancouver Island, B.C.: A complex water control structure was constructed at the lake outlet to limit high flows and augment low flows in the Big Qualicum River (Figure 17.5). An earthfill dam was built to impound water that can be withdrawn from three depths for temperature control. The water is conveyed through a tunnel to a valve house where the flow is regulated.

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18 *Stream Aeration*

Introduction

Healthy stocks and high stream productivity are dependent on well oxygenated water. While most waters contain dissolved oxygen in concentrations sufficient to support fish, oxygen levels must occasionally be artificially elevated in some systems. These include lakes susceptible to winter-kills, enhancement facilities that rear salmonids at high densities and streams with natural or pollutant-induced oxygen deficiencies. Aeration is a a common and relatively well documented technique.

Oxygen is transferred from the atmosphere to water by means of **diffusion** at the air-water interface. Turbulent waters absorb more oxygen than still waters due to the mixing of oxygen-rich surface layers with deeper, oxygen poor waters. As a result, flowing surface waters tends to contain more oxygen than still waters, while groundwaters are typically oxygen deficient. Wind can assist in the natural aeration of waters by agitating the surface of a water body.

A dissolved oxygen concentration of 9.5 **ppm** or more will provide adequate oxygen for all freshwater stages of development. Although different species and life stages are affected differently, a concentration level of 5 ppm is the lowest optimal level, below which egg mortality increases, metabolic rates decline and swimming performance decreases.

Low oxygen levels in streams are attributable to high biological and chemical oxygen demands (BOD and COD, respectively) and high water temperatures. BOD is the oxygen required to decompose organic matter, and can be related to the amount of organic pollution in a stream. COD is a measure of organic matter that is susceptible to oxidation by a strong chemical oxidant. It is also a measure of a stream's pollutant load.

Runoff from agricultural lands is the main source of pollutants that contribute to high BODs and CODs. Nutrient (both organic and inorganic) loading from agricultural lands can result in algal and bacterial blooms. Respiration and decomposition of algae and bacteria place high demands on dissolved oxygen.

Temperature influences the ability of water to absorb and retain oxygen. There is an inverse relationship between **oxygen saturation** level and temperature. As water temperature increases, it's capacity for dissolved oxygen decreases.

Various aeration techniques are discussed in this chapter, with emphasis being placed on stream aeration techniques. Large scale mechanical stream aeration is presently considered experimental.

Application

Before commencing any project involving stream aeration, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

Artificial aeration can be used in streams where fish production is limited by depressed oxygen levels and may be most beneficial in streams where pollutant loading is known to create high BOD and COD.

Due to its experimental nature, large scale mechanical stream aeration should be undertaken or directly supervised by a team of qualified engineers and biologists.

Design and Installation Guidelines

Aerators can achieve gas transfer either by passing small droplets of water through air or by passing small bubbles of air through water. The first approach provides the additional benefit of stripping undesired gases from the water. Such gases include nitrogen, carbon dioxide, hydrogen sulphide, methane and ammonia. Gas transfer efficiency can be improved in the second approach by using pure oxygen rather than air.

A variety of aerator designs have been used to oxygenate streams, however, most are complex and require that the water be removed from the stream for treatment and then returned. Two aeration techniques that are relatively simple and can be applied instream are mechanical surface aerators and diffusers.

Mechanical Surface Aerators

Mechanical surface aerators are devices that create an area of intense turbulence in which air is entrained in water (Figure 18.1). These include: turbines; propeller pumps; rotors and other similar devices that are usually floated on the water surface. Screens must be provided to prevent fish mortality. This type of aerator can impose restrictions on navigational and recreational use in larger streams and rivers.

Diffusers

Compressed air (or pure oxygen) is pumped below the water surface and released as small bubbles through perforated pipes or porous material. Maximum oxygen transfer is achieved by minimizing the size of bubbles and maximizing the water depth.

A simple, alternative approach to mechanical aeration is the installation of low head weirs to create plunge pools and turbulence (Figure 18.2). This method is effective on small, shallow streams with sufficient gradient to produce drops.

Dissolved oxygen concentrations can also be increased indirectly through temperature regulation. Trees and shrubs planted along the banks of a stream or river provide shade and reduce the potential for high surface water temperatures.

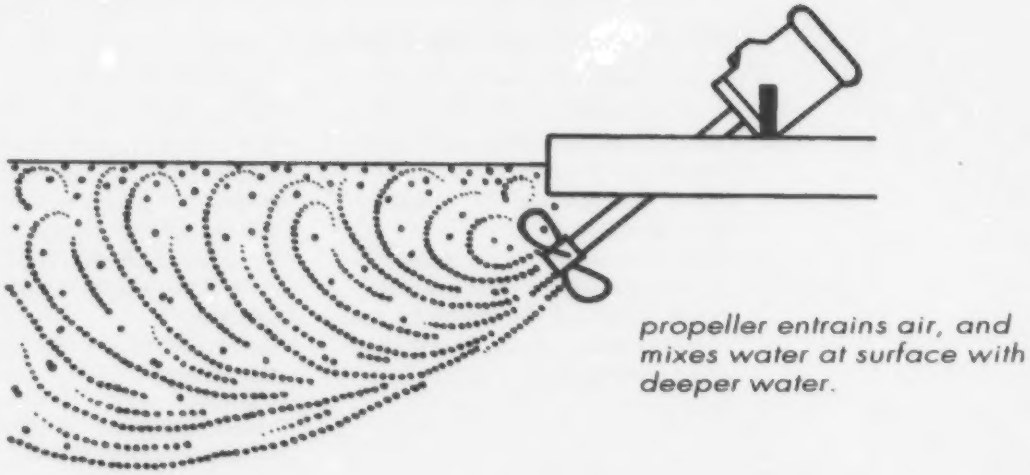

Figure 18.1 A mechanical surface aerator.

page 166

Design and Installation Guidelines

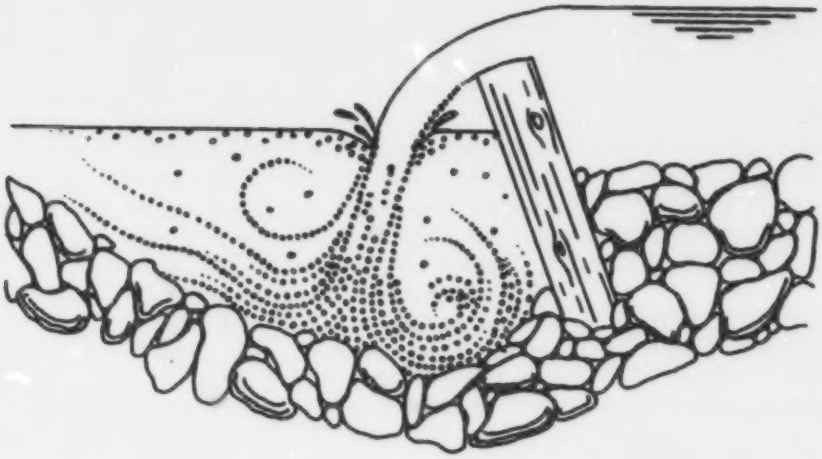

Figure 18.2 *Oxygen entrainment in water at a low head weir.*

Maintenance

Almost all aerators are mechanical devices that are powered by either engines or electric motors. Continuous operation, therefore, requires a constant power source and periodic inspection/maintenance of mechanical parts. Diffusers may require cleaning of submerged parts that may become biologically-fouled or clogged with airborne particles.

Factors Influencing Cost

- aeration systems can be purchased from commercial suppliers or be custom-designed and built to suit a particular situation
- power source; the choice between engines and electric motors as the power source will depend on the rate of consumption, period of operation and availability/cost of electricity or fuels
- degree of oxygenation required and volume (discharge) of water in the stream; the greater the oxygen deficit and the volume of water, the greater the required aeration capacity of the system; multiple installations may be necessary
- site accessibility for installation and maintenance

Advantages of Technique(s)

- aeration can increase oxygen levels sufficiently to prevent fish kills and increase the carrying capacity of streams
- continuous operation is not necessary; aeration can be implemented on an "as required" basis during periods of critically low oxygen concentrations
- aeration can be used to offset biochemical and/or chemical oxygen demands
- stream aerators are generally employed during warm weather and are, therefore, not restricted by ice conditions
- weirs are a low cost and simple approach for aerating some streams

Disadvantages of Technique(s)

- diffuser-type aerators may be susceptible to clogging or fouling of submerged components
- since the efficiency of diffuser-type aerators is related to stream depth, they tend to be ineffective in shallow streams
- navigation and/or recreational use of a stream may be restricted in the vicinity of mechanical surface aerators
- surface aerators can cause aesthetically unpleasant build-ups of foam on the water surface
- aerators may be susceptible to vandalism
- mechanical aerators require screens to prevent damage by debris or loss of fish
- monitoring and maintenance requirements are generally high
- insurance may be required to cover liability against such events as electrical shock, fuel spills or damage to boats

Examples of Use

Serpentine River, Surrey, B.C.: An experimental diffuser-type aerator was installed and operated for one year to test its efficiency in preventing fish kills attributed to low dissolved oxygen concentrations in the fall (Figures 18.3 and 18.4). Agricultural drainage in this system causes high BOD that results in oxygen deficiencies and periodic fish kills during periods of upstream migration. The diffuser was successful in raising oxygen levels in the aeration zone, however, abnormally low fall temperatures and precipitation prevented a 'worst case' scenario form being tested.

Brunette River, Burnaby, B.C.: A series of low head weirs were installed to create pools and cascades and increase turbulence. Dissolved oxygen concentrations increased as a result of these structures.

Examples of Use

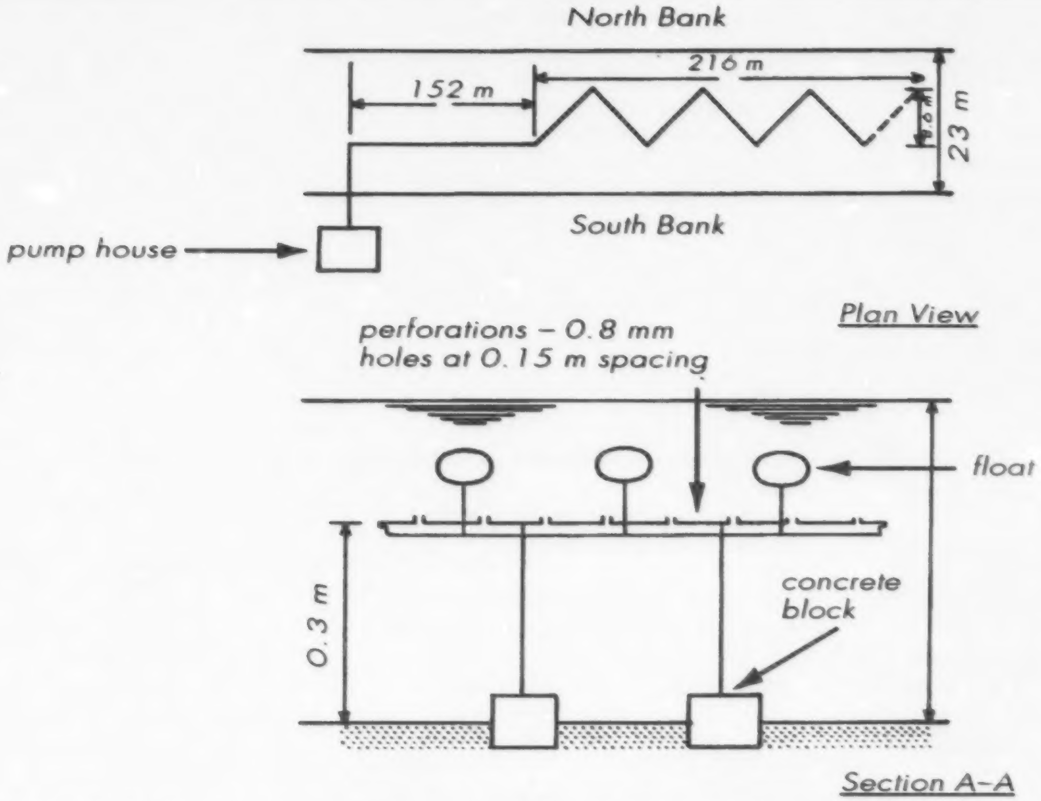
North Bank
216 m
152 m
6.0 m
23 m
South Bank
pump house
Plan View
perforations – 0.8 mm
holes at 0.15 m spacing
float
concrete
block
0.3 m
Section A–A

Figure 18.3 Design features of the Serpentine River aeration system (Town et al., 1987).

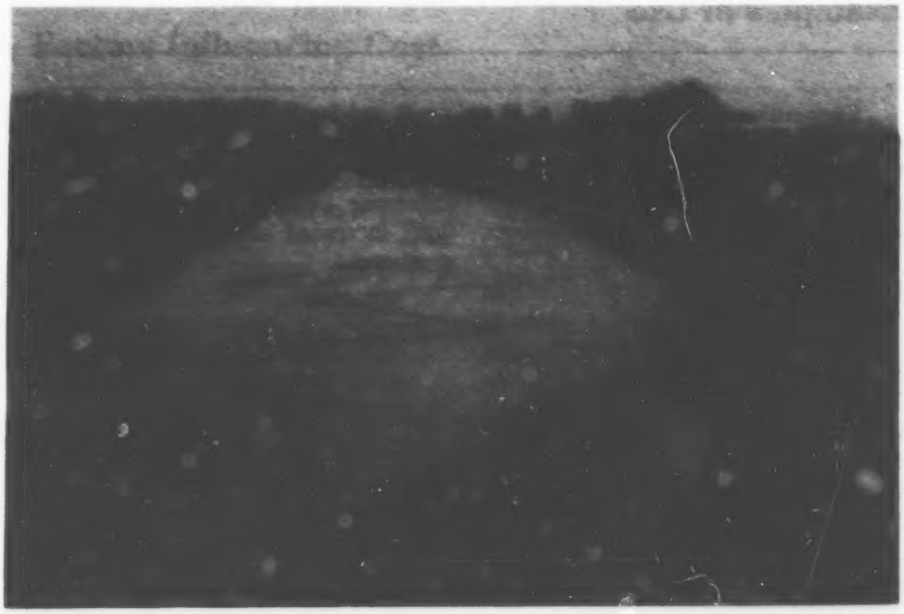

Figure 18.4 A surface view of the Serpentine River aeration system.

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19 *Marsh Creation*

Introduction

Tidal freshwater, brackish, and salt marshes are important fish habitats. They provide food and shelter to an assemblage of sport and commercial fish species.

Marsh vegetation, along with phytoplankton and eelgrass, are vehicles by which the sun's energy is converted into a form that can be used by animals. The **detrital** contribution of marshes is the major energy component of estuarine food webs. Increasing the production of detritus in turn increases the production of dependent fish species.

In addition to its value as fish habitat, marsh vegetation stabilizes sediments and provides protection against erosion from currents, **fetch** and **wakes**. The stability of many shorelines is dependent on the presence of foreshore marshes.

This chapter presents considerations and techniques associated with marsh creation in both estuarine and marine environments. Target plant species, physical and biological prerequisites, propagation methods, and site preparation are discussed.

Application

Before commencing any project involving the manipulation of foreshore fish habitats, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

Marsh creation projects that involve the placement of dredge spoil for site preparation will require direct involvement by qualified engineers during site selection and design. A qualified biologist, preferably a botanist, should be consulted in all marsh creation projects. The importance of consulting qualified professionals in the planning, design and application of marsh creation projects cannot be overstated.

Marsh creation in British Columbia is still largely experimental. Many of the techniques presented in this chapter have not been applied. For those techniques that have been applied, little quantitative information regarding their success is available. All of the techniques presented, however, have been applied in other regions of North America with success. Much of the information presented in this chapter is based on findings from other regions.

Sediment Accretion

Ideal sites for marsh creation are those areas that possess naturally **accreted** sediments and elevations conducive to marsh plant **persistence**. Potential marsh creation sites should be evaluated in terms of the possibility for, and the rate of colonization by desired native plants. Sites that are not within a suitable distance of a seed source to permit natural colonization may require artificial marsh establishment.

The potential for undesirable exotic plants species to become established at the accretion site is an important planning consideration. The most aggressive of these exotics is purple loosestrife (Lythrum salicaria). It readily colonizes newly accreted mudflats and sandflats, quickly establishing **monotypic** stands that exclude native vegetation. It degrades such backwater fish habitats as blind channels and sloughs by choking off open water areas. A qualified botanist should be consulted regarding the potential for undesirable plant establishment.

Application

Dredge Spoil

Dredge spoil can be used to increase the elevations of intertidal/subtidal habitats to those levels conducive to marsh plant **establishment** and persistence. Projects involving dredge spoil placement and stabilization require substantial technical input.

Upland Excavation

Upland areas may be excavated, and subsequently graded, to elevations conducive to marsh plant establishment and persistence. However, the opportunity to obtain suitable upland areas at a reasonable cost, especially in urban and industrial regions, is limited.

Design and Installation Guidelines

Site Selection

Ideal marsh creation sites are located immediately adjacent to existing marshes (Figure 19.1). These sites exhibit many of the physical characteristics typical of adjacent marshes. Elevation, slope, soil salinity, substrate particle size, wave force, and the nutrient regime all interact to determine the final vegetative community that will evolve at the site.

Elevation

The most important physical variable to consider for marsh creation projects is elevation. Elevation controls the length and frequency of tidal submergence. The salinity regime in estuarine environments is also affected by elevation. Most species can tolerate a broad range of intertidal elevations, however, each species exhibits a peak abundance within a different range of elevations. This creates a definite vertical zonation of plant species (see Chapter 1).

***Figure 19.1** Marsh creation immediately adjacent to existing marsh* - Garry Point, Richmond, B.C.

Design and Installation Guidelines

A **topographic** and/or **bathymetric** survey of both the creation site and adjacent marsh communities should be conducted. This data is subsequently correlated to site specific tide or water **datum**. A comparison of elevations will provide insight into the plant community that can be supported by the marsh creation site.

The potential for sedimentation and the extent to which it may affect site elevations should be assessed. A high sedimentation rate may lead to a subsequent rise in substrate elevations that in turn might contribute to the succession of plant species other than those targeted in the marsh creation plan.

Elevations are especially critical in marsh development projects that use dredge spoil. Foundation soils below the dredge spoil may compress due to the weight of the fill. The dredge material may also settle. Both **compression** and **settlement** contribute to a decrease in surface substrate elevations. The marsh creation plan must include predictions of compression and settlement, as it would be impractical to raise surface elevations with fill after the site has been seeded or planted. It is often best to let a site settle for a period of time before seeding or planting. A qualified engineer should be consulted for substrate settlement and foundation soil compression estimates.

Slope

Most estuarine and salt marshes appear flat. This topography reflects the conditions under which sediments are laid down. The same conditions that promote the deposition of sediments provide a suitable environment for marsh plants. A typical Fraser River estuarine marsh exhibits a slope of 0.1-2.0%.

Slopes typical of adjacent marshes should be incorporated into the site design.

Soil Salinity

Soil salinity is the salinity of water contained within the spaces between individual soil particles. In most instances this physical parameter is of minor concern in marsh creation project design.

In **hypersaline** areas, however, watering to reduce soil salinities should be considered. Young vegetative seeds do not survive will in hypersaline environments. Natural vegetation establishment in estuarine and coastal habitats occurs during freshet in late winter and spring when the input of freshwater decreases soil salinity. Soil salinity should be quantified to ensure that the environment will be appropriate for plant propagation.

Substrate Particle Size

In marsh creation projects that incorporate dredge spoil, an important consideration is substrate particle size. A decrease in particle size is accompanied by an increase in total particle surface area, which increases the capacity of substrate to bind nutrients. This is especially important since the limiting factor for plant growth is often nutrient availability.

There are disadvantages to using fine sediments (less than 0.04 mm in diameter: silty clay) as the rooting or planting medium. The same high surface to volume ratios that promote the incorporation of nutrients also enhance the binding of heavy metals and organic pollutants. Fine sediments also exhibit consolidation properties that contribute to the establishment of hard compacted substrates. Waterlogging and oxygen deficiencies are the result of water retention by fine sediments. All of these characteristics contribute to poor plant establishment and persistence.

Design and Installation Guidelines

Sand is favoured over fines as a rooting medium for plants. Sand allows adequate respiration for roots and greater access to dissolved nutrients. Sand, however, is often associated with nutrient poor habitats. This is especially true of marine environments. Fewer nutrients are able to bind to sand grains due to the relatively low surface to volume ratio.

Nutrient deficiency is generally not a concern in estuarine, sandy substrates. Estuarine waters contain high concentrations of suspended nutrient-rich sediments. Suspended sediments transport large amounts of nutrients to estuarine habitats. The continual deposition of these enhances the nutrient regime of sandy substrates in estuaries.

A major concern with sand is its tendency to drift. Drifting material may expose roots and displace or bury plants. Physical scour of vegetation can also occur and lead to plant death.

The ideal substrate for marsh creation appears to be a mix of fine sediments and sand. The fines consolidate the substrate and bind enough nutrients to adequately support vegetation. The sand permits adequate aeration and drainage.

Energy Regime

When considering site location, identify the depositional and erosional forces at work. Riverine and tidal currents, fetch and wake may adversely affect a marsh creation project. Ideal site location is in a low energy environment with adequate flow to minimize sediment deposition. If high energy environments are selected for marsh creation, protection from erosional processes should be provided by structures such as rock berms, log booms, and piling and timber barrier. These structures are discussed in Chapter 21.

Site Preparation

Excavation, grading and contouring of the site will require the use of heavy machinery. Hydraulic, "Hi-Hoe" and dragline excavators, bulldozers, front-end loaders, and back-hoes are but a few of the types of heavy machinery that can be used. Project requirements, access to the site and cost are factors in machinery selection.

Upland areas have the greatest potential for a diversity of habitats. Excavated material is used to create hummocks and islands. Areas designated for vegetation are contoured to appropriate elevations and planted. Substrate stability is usually not a problem with upland areas as the soils have settled and consolidated.

Marsh creation projects that use dredge spoil require the same field investigations and laboratory tests required for the design of conventional dredge material disposal areas. Substrate configuration, elevation and retention must be detailed in the site design. Fill stability will be affected by factors such as disposal site topography, wave and current regimes, and substrate foundation characteristics. These factors must be addressed to avoid compromising the long term stability of the marsh creation site.

Little, if any, manipulation of naturally accreted sites should be required if appropriate elevations are present. The site will often exhibit a hydraulic regime, substrate and slope suitable for marsh establishment and persistence. Habitat complexity may be increased by creating channels, islands and/or pools.

Litter Corridor Channels

The above ground vegetative matter in brackish and salt marshes is naturally harvested by the elements during the fall and winter months. This organic matter is washed up and deposited on the high marsh-upland interface where it often

Design and Installation Guidelines

smothers underlying vegetation that emerges in early spring. This zone of material accumulation is referred to as a **litter corridor**.

Channels, which can be constructed in the litter corridor, will accelerate debris transfer out of the area. These channels should take advantage of site features and where possible, should be aligned with an/or intersect natural drainage channels. Each little corridor channel should have an opening at each end of the marsh site. If site configuration does not permit two openings, the opening of the channel should be located at the downstream or down current end of the site. In intertidal habitats, the litter channel should have bottom elevations lower than the local mean low water level to encourage tidal flushing.

Intertidal Islands

Intertidal islands may be created either by excavating existing upland areas or by depositing dredge spoil in intertidal or subtidal environments. Islands effectively increase the amount of high marsh-upland interface which in turn increases habitat complexity (Figure 19.2).

Intertidal Channels

Intertidal channels are a natural feature of undisturbed west coast tidal marshes. They facilitate drainage and the offshore transport of detritus. They provide access and refuge for juvenile salmonids as well as other aquatic organisms. Channels increase the low marsh-water interface that in turn increases habitat complexity.

Channel construction is a viable enhancement technique in intertidal or upland locations with consolidated substrates. However, in unconsolidated materials, such as recently placed dredge spoil, channel banks may collapse.

Pools

Some marsh species thrive in standing water habitats. These include cattail (Typha latifolia), arrowhead (Sagittaria latifolia) and water plantain (Alisma plantago-aquatica).

Shallow basins or pools may be excavated to retain several centimetres of water if standing water species are preferred.

Figure 19.2 *Intertidal islands and channels - Ladner Sewage Lagoon, Ladner, B.C.*

Design and Installation Guidelines

Vegetation Establishment

Plant Species

The following recommendations apply in the selection of herbaceous plant species for use in marsh creation projects:

- select plant species of known fish habitat value
- select perennial plant species
- select plant species that optimize the broadest tidal elevation range
- select local plant species
- select plants that have been used successfully in the past

A list of common estuarine and marine plant species is presented in Appendix 1. Reference is made to the habitats and taxonomically distinguishing features of each species. Local plant species with a history of use in marsh creation projects in North America are listed in Appendix 2.

Plant Propagules and Planting

The following factors should be considered when selecting plant propagules for marsh creation:

- plant species selected
- propagule availability
- exposure of the site to waves and currents
- cost
- timing

Commonly used propagule types include seeds, sprigs, rhizomes, tubers, plugs, sods, peat pots, and cuttings. For those propagules that require extraction of vegetative material from adjacent marshes, care must be taken to minimize the impact on the donor community. Heavy machinery should never be used on donor sites. Damage caused by the machinery would detract from the benefits of habitat creation. Material should be extracted at intervals that will allow for quick re-establishment of vegetative cover. Holes resulting from excavation should be filled with substrates suitable for plant growth.

Seeds

In general the seeds of marsh plants are best stored wet under refrigeration. Uniform distribution of wet seeds is difficult as the seeds tend to clump together. Mixing wet seeds with clay-based cat litter, dry sand, or other inert drying material improves uniform distribution.

Seeding should be performed in early spring with most plant species. Seeds should be broadcast at low tide with 1 to 3 cm of **tillage**. Seeds that are surface sown will float or wash away at high tide. Seeding should only be attempted in environments that are sheltered from excessive wave activity.

Sprigs

A grass or sedge sprig is composed of a single stem and associated roots, a basal shoot and short rhizome sections (Figure 19.3). For transplanting, the stem should be trimmed to 15-30 cm in length.

The roots of many herbaceous plants are annual. When the sprigs are excavated, old roots may be stripped from the stem and/or rhizome. Care should be taken when handling new roots. New roots are white or light in coloration. Old roots are dark and often exhibit tissue death and rot.

Tubers and Rhizomes

Tubers and rhizomes are underground vegetative parts of perennial plants (Figure 19.4). Transplants of tubers and rhizomes should be performed during winter and spring when the plants are dormant or in the early stages of growth. Viable propagules have light coloured bulbs and shoots. Healthy tubers are hard while healthy rhizomes are somewhat elastic.

Design and Installation Guidelines

Figure 19.3 A sedge sprig

Figure 19.4 A cattail tuber

Plugs and Sods

Plugs may be cylindrical or cubical in shape. They are composed of stems, roots, underground perennial parts and associated substrate (Figure 19.5). A common device for extracting plugs is a golf green cup cutter (cylindrical plug 10 cm in diameter X 20 cm long).

Sods are also composed of stems, roots, underground perennial parts and associated substrate. Sods size is variable depending on the method of extraction and mode of transport. Sods may be extracted using spades or other sod cutting device.

Peat Pots

Peat potted nursery stock is composed of peat pots filled with sand or other potting mixture which have been sprigged and/or seeded with a desired plant species. Other types of unit containers are currently being evaluated (Figure 19.6). During culture, peat pots are immersed in water until the plants are well developed (i.e. with a minimum stem length of 14 cm and a root mass extending through all sides of the pot). For salt marsh species, sodium chloride is added to water until the desired salinity is achieved. Water salinity is controlled by adding freshwater to replace evaporated water.

Design and Installation Guidelines

***Figure 19.5** A sedge plug*

Figure 19.6 Carex Lyngbyei *seed germinated in Rootrainers - sometimes referred to as "book planters"*

Design and Installation Guidelines

Marshes near the proposed creation site are the ideal source of native material to establish nursery stocks of grasses, sedges and rushes.

Cuttings

Cuttings are clipped above-ground vegetative material that are taken from marsh species that naturally root from nodes or develop roots from vegetative fragments. Cuttings are raked into the substrate of the marsh development site. As with seeds, cuttings should only be used in low energy environments, to avoid the risk of washout.

Fertilization

Fertilization may be necessary at some sites that typically suffer from low nutrient concentrations (i.e. salt marsh/sand substrate, lake marsh). The use of fertilizers in west coast marsh creation projects, however, has been limited. Lynbye's sedge (Carex lyngbyei) and pickleweed (Salicornia virginnica) have been reported to be responsive to fertilizer treatments. Much more research is required to determine whether fertilization is a viable technique for marsh creation projects within the region.

Monitoring of the marsh creation sites will determine whether a maintenance program is required. Maintenance might include the control of herbivores, the eradication of undesirable plant species, removal of accumulated debris, and the planting of secondary propagules where initial planting was unsuccessful. Sedimentation and erosion can be quantified and corrective measures taken if necessary. Monitoring of marsh creation sites should be performed for at least 3 years.

Factors Influencing Costs

When estimating the cost of any marsh creation program, the time of year when the work is to be performed, site size, materials, and required equipment should all be considered.

The computed cost of a marsh creation program should consider cost per plant and projected areal coverage. Some planting strategies initially cost less than others. Subsequent evaluations of the site several growing seasons after planting will reveal the degree of vegetative expansion. These long term results may significantly affect the final cost per plant ratio.

A typical situation where one marsh creation technique may initially cost more than another, yet in the final evaluation be less expensive, is when comparison is made between large sods and sprigs. The sods require little preparation time relative to the time to extract and plant individual sprigs. Sods, on a cost per shoot ratio, initially are less expensive than sprigs. However, each sod unit has only a limited perimeter from which to expand. Individual sprigs can initially expand in any direction without restriction. Both transplant techniques may initially establish 1000 shoots, but the sprig technique will result in a greater number of shoots established and greater areal coverage.

Factors influencing cost are presented :

Site Preparation

Upland Habitats

- land acquisition costs
- heavy machinery costs
- consultant fees

Factors Influencing Costs

- time of year (tides determine the amount of time available to work in the intertidal zone)

Dredge Spoil Habitats

- heavy machinery costs
- dredge spoil port authority royalty fees
- dredging and transport fees
- actual dredge spoil purchase fees
- consultant fees
- retention/protection structure costs
- time of year (tides determine accessibility to dredge disposal site by dredge and barges)

Naturally Accreted Habitats

- heavy machinery costs if channelization or intertidal island creation is planned
- consultant fees
- time of year (tides determine the amount of time available to work in the intertidal zone)

Vegetation Establishment

- plant species selected
- accessibility to donor marsh/availability of plant material
- propagule type
- natural vs. cultured stocks
- use of fertilizers (if required)
- time of year (tides determine the amount of time available to work in the intertidal zone)

Advantages of Technique(s)

Site Preparation

Upland Habitats

- technically simple
- converts habitat that would otherwise have no potential as wetland habitat

Dredge Spoil Habitats

- substantially increases total area available for marsh development
- beneficial use for dredge spoil

Naturally Accreted Habitats

- natural processes that result in the deposition of sediments are usually conducive to marsh establishment and persistence
- no habitat complexing: no site preparation costs
- habitat complexing is technically simple

Propagules and Planting

Seeds

- least labour intensive
- least expensive
- suitable for large sites

Rapid Collection

- may be stored for several months
- least disruptive to the donor community

Sprigs

- relatively easy to obtain
- less costly than plugs

Tubers and Rhizomes

- maximizes use of plant material (stored energy reserves for new growth)
- good probability of success

Advantages of the Technique(s)

Plugs and Sods

- rapid establishment
- high probability of success
- greatest tolerance to grazing pressures

Peat Pots

- as cultivation is usually from seeds, it too also has the least impact on the donor community
- may be planted any time of year
- time delays in site preparation will not affect success of plant establishment
- storage in nursery or greenhouse

Cuttings

- next to seeds, least labour intensive
- next to seeds, least expensive
- rapid collection
- next to seeds, least disruptive to the donor community

Disadvantages of Technique(s)

Site Preparation

Upland Habitats

- land acquisition costs
- heavy machinery costs

Dredge Spoil Habitats

- most expensive site preparation alternative
- heavy machinery costs
- dredge spoil/dredging costs
- retention/protection structure costs
- engineering/technical expertise required

Propagules and Planting

Seeds

- wide range of viability, reliability, and success
- harvest time restrictions
- planting time restrictions
- storage facilities required
- requires a long handling period

Sprigs

- must be planted promptly or potted and stored
- disruptive to donor community

Tubers and Rhizomes

- most difficult to locate
- susceptible to washout
- disruption to donor community
- harvest time restrictions

Plugs and Sods

- highest costs and labour requirements
- greatest disruption to donor community
- harvest time restrictions
- must be planted promptly, cannot be stored for extended periods

Peat Pots

- storage and cultivation facilities required
- next to seeds, longest handling period

Cuttings

- susceptible to washouts
- must be planted promptly or potted and stored
- less success than rooted material
- limited species application

Examples of Use

Plugs

Fraser River Park, Vancouver, B.C.: Fraser River Park is located in south Vancouver on the Fraser River. Two marsh transplants, the first in February, 1986, the second in March, 1987, have been performed at the site.

The donor site for the transplants was Wood Island Slough (located on the north side of Sea Island immediately across the North Arm of the Fraser River from the recipient site).

The 1986 transplant involved approximately 2,125 plugs of Carex lyngbyei, 450 plugs of Scirpus validus, and 4,425 plugs of Juncus balticus. The 1987 transplant involved 1040 plugs of C. lyngbyei, and 1,660 plugs of J. balticus. Plugs were extracted with a golf green cup cutter.

Some propagule failure has occurred. This is due to poor substrate quality in some areas of the transplant site. One area is characterized by shifting sand that buries some plugs and exposes others to displacement by erosion. Another area is characterized by cobble and broken concrete and clay bricks. Plugs planted in this region experienced a net loss of sediment, resulting in exposed roots and subsequent breakdown of the structural integrity of the plugs.

Plug success is exceptional in areas characterized by substrates of mixed sand and clay. Plugs have vegetatively expanded and grown completely together within 2 growing seasons.

Tilbury Island mud/sandbar, Ladner, B.C.: The Tilbury Island mud/sandbar is located immediately downstream of Tilbury Slough in the main arm of the Fraser River. Plugs were extracted utilizing a golf green cup cutter. In March 1988, 1,820 plugs of C. lyngbyei, Juncus articulatus, J. balticus, Typha latifolia and Iris pseudacorus were transplanted from donor sites immediately downstream of Tilbury Slough to a recipient site located at the upstream end of the sandbar.

Preliminary results indicate poor transplant success with J. articulatus and good transplant success with C. lyngbyei. The poor performance of transplanted J. articulatus may be associated with a lack of freshwater seepage at the recipient site. The donor site for this plant is characterized by freshwater seepage from adjacent upland habitat.

Nathan Slough, Matsqui, B.C.: A tidal fresh marsh was created in Nathan Slough, immediately downstream of the Glen Valley pump station. Plant species were selected according to their palatability to domestic geese that frequent the area. Geese prefer to graze on grasses and sedges (Carex). Therefore, emphasis was placed on more coarsely fibered species such as Typha latifolia, Scirpus microcarpus, and Juncus effusus. Donor material was extracted with a golf green cup cutter.

Preliminary observations indicated early success of the transplant. Unfortunately, cattle gained access to the site, and used the marsh bench as platform for drinking from the slough. The marsh vegetation was trampled and all transplanted material was lost by the end of the first growing season.

Garry Point Park, Richmond, B.C.: In April 1988, upland fill was excavated down to elevations conducive to marsh plant persistence. Excavated rip rap was used to create protection berms for the site. Pre-transplant analysis of the site substrates revealed soil composition suitable for marsh plants.

A total area of 1,767 square meters was planted with plugs. Approximately 6,700 plugs were planted at 0.5 m intervals. The transplant species was Carex

Examples of Use

lyngbyei. Preliminary monitoring of the site indicates more than 90% success rate of transplanted material.

Plugs and Sods/Dredge Spoil Placement

Mitchell Island, Vancouver, B.C.: In early 1988, dredge spoil was placed at a site on the south shore of Mitchell Island in the North Arm of the Fraser River. Marsh vegetation was salvaged from a foreshore development site with a "drag line" excavator. The marsh was cut into sods and transported to the recipient site by flatdeck truck (Figure 19.7). The sods were either planted directly into the dredged material, or cut into 10 cm X 10 cm plugs using spades and then planted (Figure 19.8). The total area planted equals approximately 2.0 ha. Transplanted species included S. validus, T. latifolia, and C. lyngbyei. A log boom, functioning as a wave abatement and debris barrier structure, extends around the front of the site (Figure 19.9). Preliminary monitoring has indicated good transplant success.

Plugs/Dredge Spoil Placement

Steveston Bend, Richmond, B.C.: In February and March, 1980, Public Works Canada disposed of approximately 40,000 cubic meters of spoil at a site located on the immediate north side of the Steveston North Jetty, at Steveston Bend, in the Fraser River. Spoil placement was to a maximum height of 2.3 m above geodetic zero and at an approximate slope of 0.05 (or 1:20).

The dredge spoil was planted with marsh plants almost immediately after placement. Plugs were extracted from donor sites using a golf green cup cutter. A total of 718 Carex lyngbyei and 1,366 Scirpus americanus plugs were planted.

The site was not provided with sufficient time and protection for the substrate to stabilize prior to transplanting. Within three months of the transplant many of the plugs were lost, buried or exposed as the spoil material eroded. The project did not result in the creation of any new marsh habitat.

Figure 19.7 Marsh plant salvage, extracted sods – Mitchell Island, Richmond, B.C.

Examples of Use

Deering Island, Vancouver, B.C.: In late spring/early winter 1989, 0.34 ha of low intertidal sandflat immediately downstream of Deering Island in the North Arm of the Fraser River was enclosed within a large rip rap berm and sheer boom (Figure 19.10). Dredge spoil was placed in the bermed area during October-November 1989.

Figure 19.8 Planting cut sods – Mitchell Island

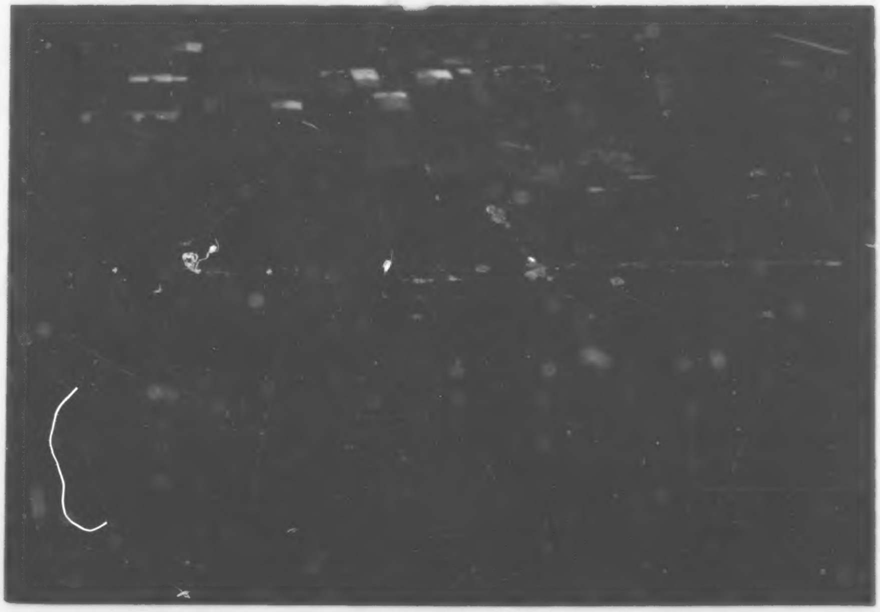

Figure 19.9 Log boom – Mitchell Island

Examples of Use

Figure 19.10 Rip rap berm and sheer boom – Deering Island, Vancouver, B.C.

Figure 19.11 Dredge spoil graded to elevation – Deering Island

The following March 1990, the dredge spoil was graded to elevations conducive to marsh plant establishment and persistence using a small "Hi-Hoe" excavator (Figure 19.11). After grading, the enclosed area was planted with Carex lyngbyei plugs at 0.5 meter intervals. Plugs were extracted from donor marshes with a golf green cup cutter. The site will be monitored for 3 years.

Examples of Use

Plugs and Sods/Intertidal Islands

Campbell River estuary, Campbell River, B.C.: The marsh creation project involved the creation of four intertidal islands and one supratidal island. The intertidal islands were planted with local marsh plant species.

Project construction commenced in September, 1981 when log debris and bark accumulations were removed from the rehabilitation site. In November, 1981, marsh transplant donor material was removed from a marsh that was to be alienated by a new log sorting facility. Vegetative material was excavated by a large hydraulic excavator. Excavated sods were approximately 1 m X 2 m X 20 cm in dimension and weighed about 1 tonne each. The sods were placed by the excavator on large metal pallets on the back of a flat deck truck and then transported to a specifically constructed overwintering area. A front-end loader equipped with log handling tynes was used to pick up each pallet off the truck at the overwintering area. A total of 350 sods were lifted and stored. The overwintering area had the same tidal elevations and water salinities as the donor site.

Island construction commenced in November, 1981, and was completed in February, 1982. Gravel and fine material from the river was excavated using a backhoe. The material was transported by dump trucks and used to build a causeway out to the proposed island locations. The causeway was subsequently spread by bulldozers at low tide to create the islands. Approximately 30,000 cubic meters of material was used to build the islands.

The total area incorporated by the islands is 3.2 ha. The islands were designed with 4:1 side slopes and a slight smooth crown to ensure proper drainage at low tide. The elevations of the intertidal islands are between 2.5 and 4.0 meters below zero tide. The supratidal island is approximately 6.0 meters above zero tide.

Immediately prior to planting, approximately half the sods were cut into 15 cm X 15 cm X 20 cm plugs and packed into plastic milk carton carriers for transport. The other half of the sods were cut into 30 cm X 30 cm X 20 cm sections. These sections were later quartered at the planting site.

Two herring skiffs and 2 wooden floats were used to transport the planting material to the planting sites. A total of 23,302 plugs were transplanted. Three planting schemes were used: 1) plugs planted at 1 meter intervals; 2) plugs planted at 0.5 meter intervals; and 3) no control plots where no planting occurred. Targeted plant species were Juncus arcticus and Carex lyngbyei.

By July 1982, 29 species of vascular plants were found on the islands. The dominant species in terms of frequency were C. lyngbyei (76%), Eleocharis palustris (55%), Potentilla pacifica (42%), and Juncus balticus (39%). The proportion of successful plugs in mid-August 1982 was 92.5%. By 1985 coverage in the 0.5 square meter plots was total. Bare soil was still evident in the 1.0 square meter plots. The 0.5 square meter plots one year after planting resembled the 1 square meter 4 years after transplant.

Ladner Sewage Lagoon, Delta, B.C.: In February, 1990, 6 ha of a domestic sewage lagoon was restored to intertidal estuarine wetland. Sewage effluent ceased to be discharged into the lagoon in 1986. Analysis of lagoon substrates revealed low concentrations of heavy metals.

Examples of Use

Tidal channels were excavated throughout the lagoon. Sidecast material was used to create approximately 60 islands and berms of various sizes . These islands and berms were planted with 724 shrubs and trees and 350 wattles.

The lagoon project is part of a research study evaluating the relative success of marsh transplants at different planting densities. Approximately 10,000 sedge (Carex lyngbyei) plugs were transplanted at 0.5, 1.0 and 2.0 meter intervals during February-March 1990 (Figure 19.12). The plugs were extracted from donor marshes using a golf green cup cutter. The study will evaluate the marsh transplants for 5 years.

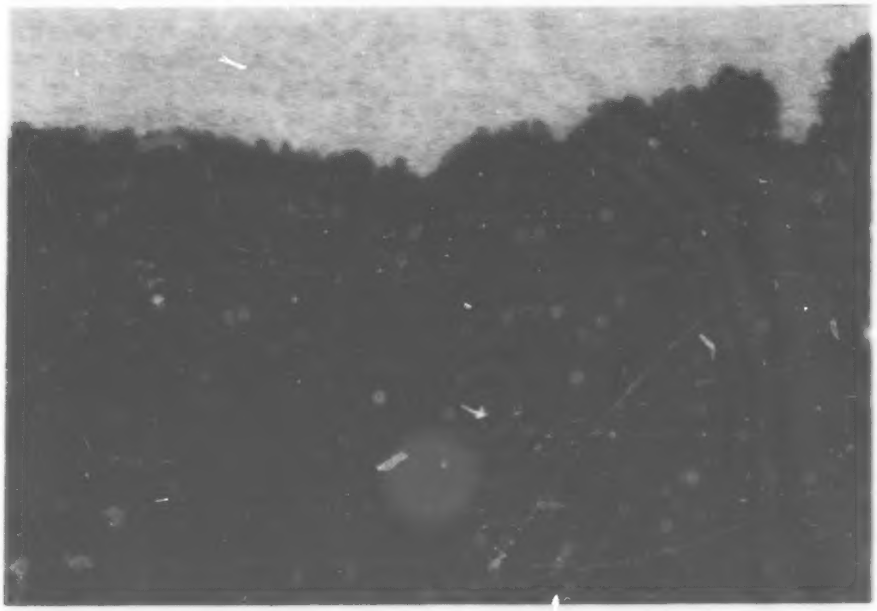

Figure 19.12 Transplant plot at 0.5 metre interval

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20 *Access Improvement*

Introduction

Dykes, berms, causeways, revetments, and other structures have alienated vast areas of estuarine fish habitat. Productive aquatic ecosystems have often been converted to land uses. A common example is dyking estuarine wetlands for conversion to agricultural land (Figure 20.1).

Habitat restoration may be possible at sites where land use activities no longer occur. The primary objective in restoration programs of this nature is to re-establish unrestricted access to the site for juvenile fishes.

Improved access is usually accomplished by breaching a barrier structure such as a dyke or berm. Accessory channels are often excavated to enhance tidal flushing and increase rearing area (Figure 20.2).

This chapter presents project considerations and techniques associated with barrier removal and channel activation in estuarine and marine environments.

Figure 20.1 *Vast areas of estuarine wetlands have been dyked for conversion to agricultural land.*

Introduction

Figure 20.2 Channels are often excavated to enhance tidal flushing and increase flushing area.

Application

Before commencing any project involving the manipulation of intertidal and/or subtidal fish habitat, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that must be consulted regarding the proposed project (Chapter 2).

Environments that benefit include:

- low lying dyked agricultural fields;
- discontinued sewage lagoons;
- discontinued log storage areas;
- old tidal channels and wetland basins blocked by dykes, revetments, causeways, log debris, and other barriers.

Design and Installation Guidelines

A qualified engineer should be consulted regarding breach opening and/or channel(s) design. Flow exchange rates and substrate composition will influence the design and determine whether or not bank stabilization is required.

Reactivation of Intertidal Marsh Habitats

The majority of alienated habitats in the estuarine environment were once productive intertidal marsh. Land uses often change some of the physical parameters of these habitats. These include substrate elevation, organic and inorganic soil com-

Design and Installation Guidelines

position and soil salinity. These all interact to determine whether or not historical habitats can become successfully re-established.

A topographic survey of the site should be conducted before a project plan is developed. Land use related activities may have altered substrate elevations. Substrate elevations directly determine the **inundation regime** of a site. The inundation regime, in turn, directly determines what plant species can become established at the restoration site. Substrate elevations typical of the restoration site should be compared to elevations of substrates supporting desirable marsh vegetation in adjacent natural wetland communities.

In brackish and saltwater environments, soil salinities of the proposed restoration site and those of adjacent tidal marsh communities should be determined. This is especially important where marsh vegetation already exists within the restoration site, as is often the case with abandoned agricultural fields and discontinued sewage lagoons. Marsh communities within such sites often differ significantly in species composition from adjacent tidal marshes. This is often due to freshwater retention and the lack of brackish or saltwater seepage into the proposed restoration site. If soil salinity within the site differs significantly from the outside environment, a gradual change in plant species composition should be expected as unrestricted tidal flushing occurs within the site.

Gradual changes in species composition will also occur if substantial standing water exists within the proposed restoration site. Some marsh plant species prefer standing water and the stable water regime it provides. Barrier removal and channelization will enhance drainage and re-establish tidal flushing. Those marsh plant species tolerant of the fluctuating water regime characteristic of tidal environments will dominate the restoration site. Potential changes in plant species composition should be addressed in the project plan.

Soil types and their composition should be determined. Previous land use activities may have deteriorated soil quality. Sewage lagoon soils are of special concern. They are characterized by large amounts of organic material and high concentrations of heavy metals. **Anaerobic** conditions associated with high organic content and the toxic effects of high concentrations of heavy metals may adversely affect the establishment of vegetation and fish use of restored habitats.

A high organic fraction is also typical of abandoned agricultural field soils where the water level fluctuates near the soil surface for most of the year. Marsh plants become readily established in such soils and subsequently produce vast amounts of organic matter. The lack of rapid turnover in standing, surface, or near-surface water creates anaerobic conditions within the soil. The decomposition rate of organics in such anaerobic soils is severely depressed, and as a result, a large organic layer often accumulates over time. Exposure to **fluvial** drainage and tidal flushing oxygenates the organic matter which increases the decomposition rate. Decomposition soon supersedes accumulation. Where a significant organic base is present, increased decomposition can decrease substrate elevations. Potential decreases in substrate elevations should be addressed in the project plan.

A 'Gradall' or 'Hi-Hoe' excavator is used to breach barrier structures and excavate channels. The following steps are recommended:

- mark the alignment of channel(s) with stakes and surveyor's flagging tape;
- excavate the channels before the barrier structure is breached, this avoids stranding machinery in wetted areas;
- side cast excavated material to an area

Design and Installation Guidelines

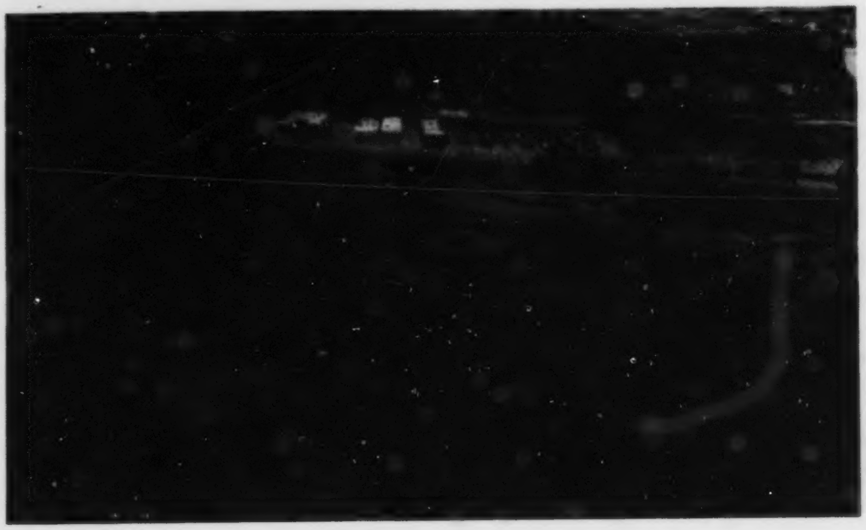

Figure 20.3 Wetland edge can be increased by creating small islands with excavated material.

adjacent to the channel, this avoids unnecessary disturbance of habitat associated with off-site removal; small islands may be created with the excavated material thereby increasing **wetland edge** (Figure 20.3);

- provide a survey team on-site to ensure that excavation meets with proposed site elevations and channel design;
- if a marsh transplant is part of the restoration project, perform the transplant before the barrier structure is breached;
- breach the barrier structure at low tide to minimize erosion caused by initial movement of water into the restoration site; ensure that elevations of the opening permit fish to access restored habitats at most tidal levels.

Tidal Channel Reactivation

Channels are often completely alienated from tidal exchange by the construction of dykes, berms, causeways and revetments. Partial restriction of tidal exchange also occurs through some manipulation of channel habitat, as is often the case when channels are used for log storage. Restoration of fish habitat in such instances can be accomplished by removing the barrier and/or eliminating activities within the channel that are limiting tidal exchange and subsequently fish access.

For those areas that are not easily accessible by land, and/or have substrate that can not support heavy machinery, a drag-line crane or dredge may be necessary to remove a barrier. Two considerations essential to the success of such a project are:

- ensuring that elevations of the opening permit fish to enter the desired habitat at most tidal levels;
- ensuring that the processes and events that were responsible for the obstruction are not likely to recur.

Habitats that are alienated by road, railway, and jetty structures may be physically linked to open water habitat by installing of a culvert or bridge at some point along the obstruction. A back-hoe, 'Gradall', or 'Hi-Hoe' type excavator may be used to excavate the breach and install a passage structure. Project considerations include:

- having a survey team on site to ensure that excavation elevations are correct;
- ensuring that passage structures accommodate all flows;
- excavating the breach during low tide.

Maintenance

A properly designed access improvement project requires little upkeep. In some instances, where substantial stands of deciduous trees exist, beavers may attempt to dam a channel or breach. The animals will have to be removed if unrestricted flow is required at the project site. If the site is susceptible to debris accumulation, it may be necessary to install a shear boom or other debris barrier at the main channel opening. Shear boom installation is presented in Chapter 21.

Factors Influencing Cost

- accessibility to the site
- physical working conditions (e.g. saturation level of soils)
- heavy machinery costs
- accessibility of site to heavy machinery; transport costs associated with barge transport
- extent of excavation
- engineering design and material costs if bridge or culvert required

Advantages of Technique(s)

- little maintenance required
- a large area may be restored at low cost

Disadvantages of Technique(s)

- high construction costs if bridge or large culvert is required: engineering design; material and heavy machinery costs
- high transport costs if heavy machinery has to transported to the site by barge

Examples of Use

Englishman River, Parksville, B.C.: A dyke preventing tidal inundation of about 40 ha of former estuarine marsh was breached in March, 1979. The project's objective was to provide significant estuarine rearing habitat for juvenile salmonids and other fish species.

Upland grasses, herbs, shrubs and trees had colonized habitat behind the dyke. Freshwater runoff was directed through former estuarine channels and exitted the dyked area through a one-way flap gate. Freshwater marsh plant species such as cattail, softstem bulrush and reed canary grass dominated channel habitat. Some remnant estuarine plant species, however, were still present (e.g. Lyngby's sedge).

Following the breaching of the dyke, saltwater (25 parts per thousand) began

Examples of Use

inundating the site. Rearing chum immediately utilized the habitat. Adult chum subsequently spawned in the upper portion of the reactivated slough.

Most of the upland vegetation and freshwater marsh was killed in the first year. By 1983 the dominant marsh plant species was tufted hairgrass. Preliminary field study results in 1986 indicate that more salt tolerant plant species were increasing in cover and frequency.

Tilbury Slough, Ladner, B.C.: A dyke constructed in the late 1800's alienated 5 ha of high intertidal marsh adjacent to Tilbury Slough. The dyked marsh was dominated by cattail, willow, and red alder. The intertidal marshes outside the dyke along the slough margin were dominated by sedge, softstem bulrush and baltic rush.

The dyke was breached and drainage canals were excavated in November, 1985. The objective of the restoration work was to increase the export of organic matter and provide additional rearing and feeding areas for juvenile salmon.

Preliminary monitoring results indicate that juvenile chum, chinook, pink, and sockeye salmon actively feed in the channels. A net export and import of detritus was observed in late winter/spring and summer, respectively.

Kokish River estuary, Beaver Cove, B.C.: During the early 1900's a dyke was constructed across the Kokish River estuary to facilitate log handling in the area. A railway trestle bridge spanning a narrow channel had permitted tidal inundation of the dyked area with salt water since 1954. Freshwater input had been limited to precipitation and the discharge of a few small creeks.

The dyke was breached in April, 1985. The main objective of the project was to decrease the salinity of the soil and accelerate the transition from a salt marsh (characterized by species such as pickleweed and arrowgrass) to a brackish water marsh (characterized by Lyngby's sedge).

Sedge abundance within the restoration area occurred within 15 months of dyke breaching. However, most vegetation changes were minor. Soil salinities and organic matter did not decrease during this period.

Ladner Sewage Lagoon, Delta, B.C.: In February, 1990, 6 ha of a domestic sewage lagoon was restored to intertidal estuarine wetland (Figure 20.4). The dyke was breached at two (2) locations. Tidal channels were excavated throughout the lagoon. Side-cast material was used to create approximately 60 islands and berms of various sizes.

The lagoon project is part of a research study evaluating the relative success of marsh transplants at different plant densities. The study will evaluate the marsh transplants and changes in existing vegetation for 5 years.

Examples of Use

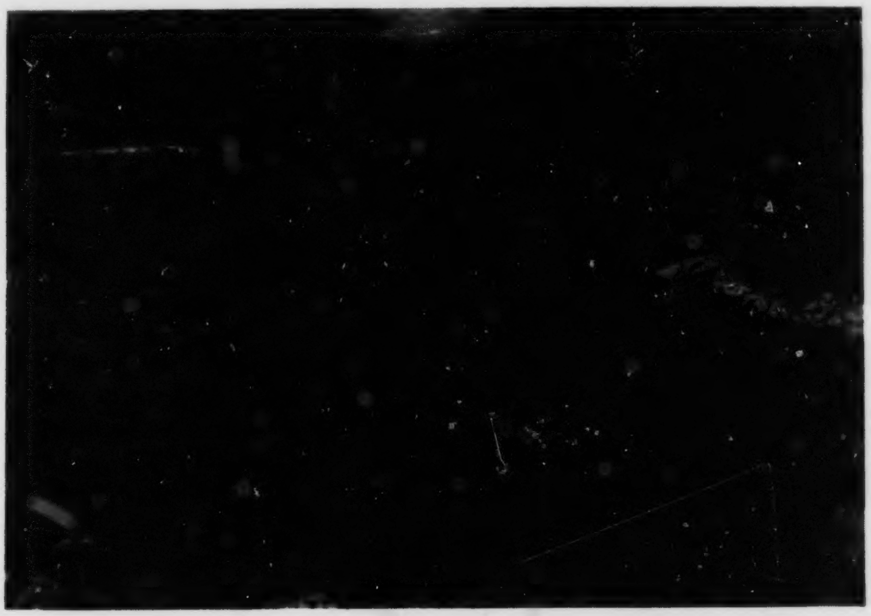

Figure 20.4 Breach opening with small sheer boom (top); channel and island close-up (bottom) - Ladner Lagoon.

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21 *Woody Debris and Erosion Protection*

Introduction

Woody debris and erosion caused by boat wakes severely impact intertidal habitats in industrialized estuaries and coastal marine areas. Physical protection is often required to restore the productive capacity of impacted habitats.

Woody debris is constantly released into estuarine and coastal marine habitats. Though some of this debris is natural, the majority of it originates from log transport/storage and milling activities.

Small debris, such as wood chips and bark fragments, smothers mudflats and marshes. Large debris, such as logs, scours or compacts mudflats and marshes. Both types of debris eliminate marsh vegetation and maintain intertidal sediments in a constant state of flux. Both conditions prevent the establishment of persistent, productive benthic communities. Woody debris decreases the productive capacity of intertidal habitat (Figure 21.1).

Debris removal temporarily restores intertidal habitats. Debris is transported to an upland disposal site. Debris removal is only truly effective when it is associated with the construction of a permanent structure that will prevent deposition of woody debris on restored habitats.

Wood product industries and other water dependent commercial activities create a significant amount of boat traffic in estuarine and coastal marine habitats. Wave associated erosion caused by boat wakes inhibits the establishment of new marsh habitat and degrades and destroys existing fish habitat.

Sheer boom, piling and timber walls and rock berms/groins are among the structures that can be constructed to prevent debris accumulation and minimize erosion. Sheer logs consist of logs attached end to end secured to pilings and dolphins. Piling and timber walls are vertically stacked pilings or timbers driven into bottom substrates to form a wall-like structure. Rock berms and groins are raised areas of ground composed of a granular or angular cobble core armoured with large angular boulders.

This chapter discusses the use of sheer booms, piling and timber walls, rock berms/groins, and debris removal.

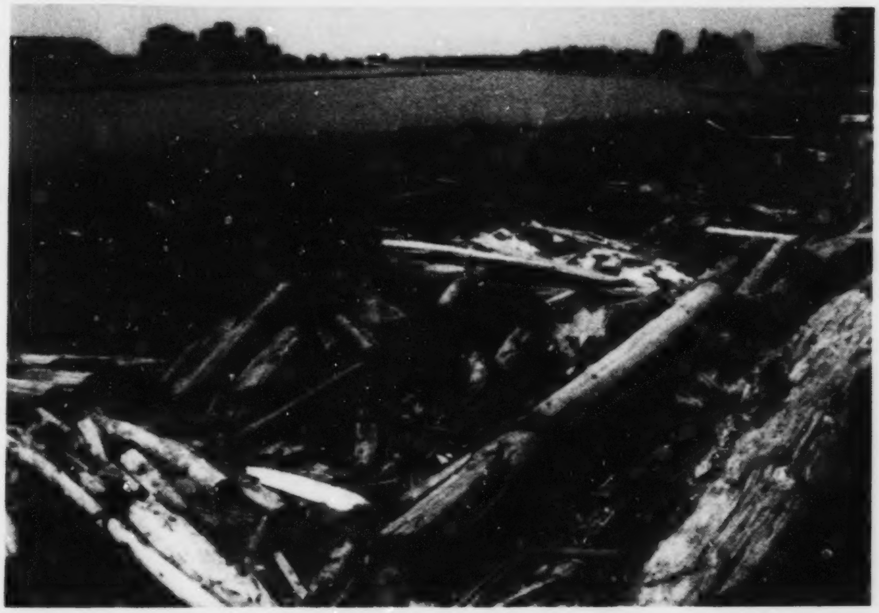

Figure 21.1 Large accumulations of woody debris significantly decrease the productive capacity of intertidal habitat

Application

Before commencing any project involving the manipulation of intertidal and/or subtidal habitats, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will the identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

Correct design and installation of erosion protection and debris barrier structures requires the expertise of structural and hydraulic engineers. A detailed feasibility study should be performed. Detailed engineering drawings are required by regulatory agencies before project review is considered.

Sheer booms are best used in situations where the primary objective is to minimize debris deposition and decrease wave associated erosion. Areas with a history of debris accumulation are prime candidates for boom installation. These areas often include the upstream and downstream ends of sloughs, back channels and embayments as well as intertidal habitats immediately adjacent to log storage and milling operations.

Existing pilings and dolphins in log storage areas can be used to anchor floating logs to form an effective barrier structure. The logs would be attached on the landward side of the storage sites.

Piling walls or piling supported timber walls may be used as deflector structures or groins that extend perpendicular to the shoreline.

Rock berms have been used, as part of larger habitat creation projects (e.g. marsh creation using dredge spoil), as both debris barriers and sediment retention structures. They have been used as deflection structures to direct debris and currents away from a specific area. Rock groins may be constructed perpendicular to the shoreline to decrease erosion in high current environments as well as facilitate sediment deposition. The rough surface afforded by rock berms dissipates energy associated with currents and waves.

Design and Installation Guidelines

Sheer boom structure design must consider the length of the boom, the wave regime and the physical configuration of the site. A pile driver is used to install the pilings (Figure 21.2). The floating logs are secured using a combination of spikes and chain links. The wooden sheer boom components are usually made of cedar logs (Figure 21.3).

Timber and piling wall dimensions vary according to site design and physical requirements. Installation is similar to that of pilings.

Fir and occasionally hemlock are used to construct in-water structures such as pilings and timber walls. Fir is the most structurally sound of available woods for construction. Untreated cedar logs are used for sheer booms. Cedar resists rot better than other wood types, however, its use is limited due to its structural weaknesses.

Pilings and timbers are often treated with a preservative, such as salt, creosote or pentachlorophenol, to increase the lifespan of the structure. Materials must not be treated on-site. Treatment must occur on a self-contained upland site. Off-site treatment eliminates the potential of spillage into fish habitat.

Design and Installation Guidelines

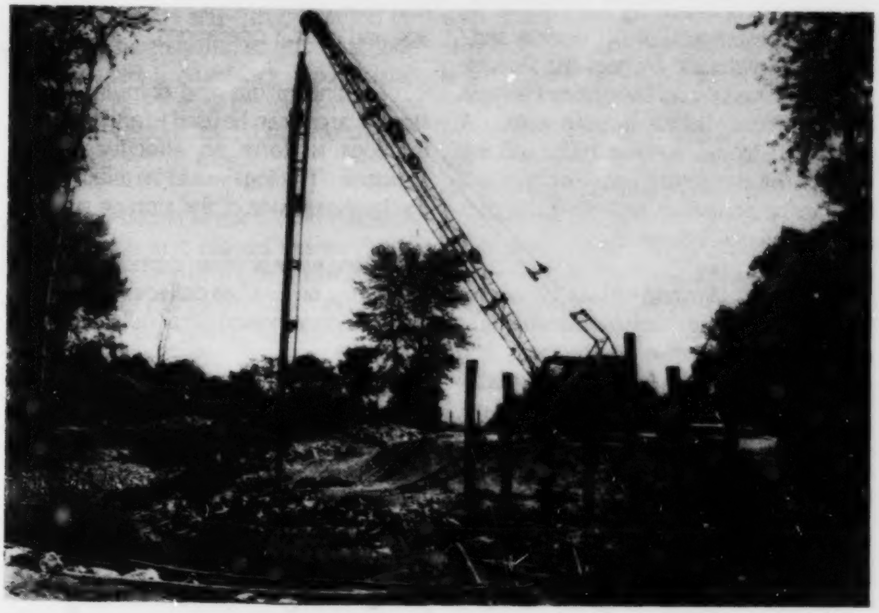

Figure 21.2 A pile driver

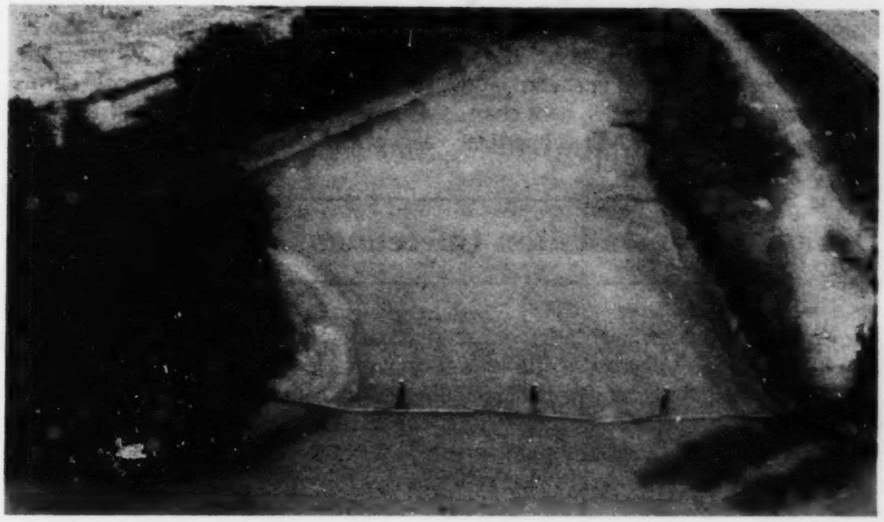

Figure 21.3 Sheer boom at Patrick Island, Delta, B.C.

Preservatives such as creosote and pentachlorophenol are toxic to aquatic organisms at low concentrations. Both accumulate in body tissues. Salt is a much less toxic alternative and does not bioaccumulate in body tissues. When considering wood preservatives, the benefit of structure longevity must be weighed against the implications of exposing preserved material to the environment.

Rock berms that are part of a habitat creation project should have openings that allow for the passage of fish, fish food organisms and detritus in and out of the creation site. The number, size and location of the openings should allow adequate drainage of the site land thereby preventing retention of water within the site. A hydraulic engineer should be consulted regarding the opening dimensions and

Design and Installation Guidelines

drainage capacity. Opening size should not be so large as to allow passage of large woody debris into the site.

Rock berm construction materials may be transported to the project site by barge and/or truck depending on site accessibility. Placement of material requires heavy machinery. For effective debris and wave protection the berm should be at least as high as the HHWL (high-high water level). The HHWL may be considered the highest water level attained during a full cycle of seasons. Berms lower than the HHWL may function as more of a debris collection device than a barrier structure.

Debris removal requires the identification of an upland disposal site and mode of debris transport. Chain saws, shovels, wheel barrows and heavy machinery may be required for debris removal. Depending on the type of debris encountered, material may be burned on location, transported via debris boom or truck to a central burn site, processed into firewood, or transported to and deposited at a landfill site.

Maintenance

Maintenance of wooden structures involves replacing components that either exhibit advanced stages of rot or pest infestation (i.e. marine borers) or have suffered damage as a result of a collision with a barge or boat.

In most circumstances, little or no maintenance is required on structures composed of rock. In some instances the foundation soils immediately beneath the rock may exhibit compression due to excessive loading. Compression may result in the collapse of some sections of the rock berm or groin. Placement of additional rock material to initial structure elevations will normally remedy the situation.

Factors Influencing Cost

Rock Berms

- site accessibility
- height of the rock berm: the higher the berm the wider the base and consequently more material and time required for installation
- availability of suitable construction material
- time of year: the least costly method of transporting and placing rock material is by barge; barge transport and placement is facilitated by daytime high tides, the highest of which occur in the winter months
- costs for engineering studies, and transportation and installation of materials

Sheer Booms, Piling and Timber Walls

- site accessibility
- wave regime: this determines the use of either pilings or the more structurally sound dolphins
- site configuration: the number of pilings/dolphins utilized per linear distance depends the structures configuration; a curved sheer boom will require more anchoring structure's than will a straight boom
- costs for engineering studies, and transportation and installation of materials

Factors Influencing Cost

- depth and length of piling/timber structure determines the degree of reinforcement required for structural integrity

Debris Removal

- site accessibility
- size and type of debris
- debris transport, distance to the disposal site and disposal method

Advantages of Technique(s)

Rock Berms/Groins

- very effective long term structure(s)
- little or no maintenance required when designed and constructed correctly

Sheer Booms

- relatively inexpensive for the function served
- effective long term structure if well maintained

Piling and Timber Walls

- inexpensive relative to similar structures made of rock
- effective long term structure if well maintained

Debris Removal

- very good short term cost/benefit ratio
- inexpensive
- technically very simple

Disadvantages of Technique(s)

Rock Berms/Groins

- high material costs
- high heavy machinery costs
- substantial cost associated with transport of materials, especially if land based
- technical and engineering expertise required to design and construct structures: feasibility report fees

Sheer Booms

- maintenance required to ensure structural integrity
- high heavy machinery costs if new pilings must be installed
- technical and engineering expertise required to design and construct structures: feasibility report fees

Piling and Timber Walls

- maintenance required to ensure structure integrity
- high heavy machinery costs
- technical and engineering expertise required to design and construct structures; feasibility report fees

Debris Removal

- short term solution that requires elimination of the causes of the initial debris deposition in order to realize long term benefits

Examples of Use

Sheer Booms

Patrick Island, Delta, B.C.: In 1986 an embayment was excavated out of Patrick Island along the foreshore of Annacis Channel, Fraser River. A sheer boom was placed at the mouth of the embayment to prevent debris accumulation (see Figure 21.3). The boom has been very effective to date.

Tilbury Slough, Ladner, B.C.: Tilbury Slough is part of the Main Arm of the Fraser River. In 1985, tidal activity was restored to dyked farmland immediately adjacent to the slough. In order to prevent debris accumulating in the numerous channels that were established in the newly reactivated area, a sheer boom was placed at the downstream opening of the slough. The boom has been effective in preventing debris accumulation in the reactivated and slough areas.

Mitchell Island, Vancouver, B.C.: Located on the south shore of Mitchell Island in the North Arm of the Fraser River, this 2.0 ha marsh creation site is protected from wave associated erosion by a sheer boom that extends into an active log storage site. This is a good example of an effective sheer boom located immediately adjacent to a log storage site.

Fraser River Park, Vancouver, B.C.: This park, located on the shores of the North Arm of the Fraser River in southern Vancouver, is the site of an estuarine tidal pond/marsh creation project. In the spring of 1989 a sheer boom was placed in front of the park to eliminate the chronic debris problem the park has experienced since 1986.

Rock Berms

Westminster Quay, New Westminster, B.C.: This relatively small marsh creation site is located in the North Arm of the Fraser River immediately fronting the Westminster Quay development in New Westminster. Created in the winter of 1987/88, it illustrates an ideal design for marsh creation in a high current environment utilizing a trough configuration.

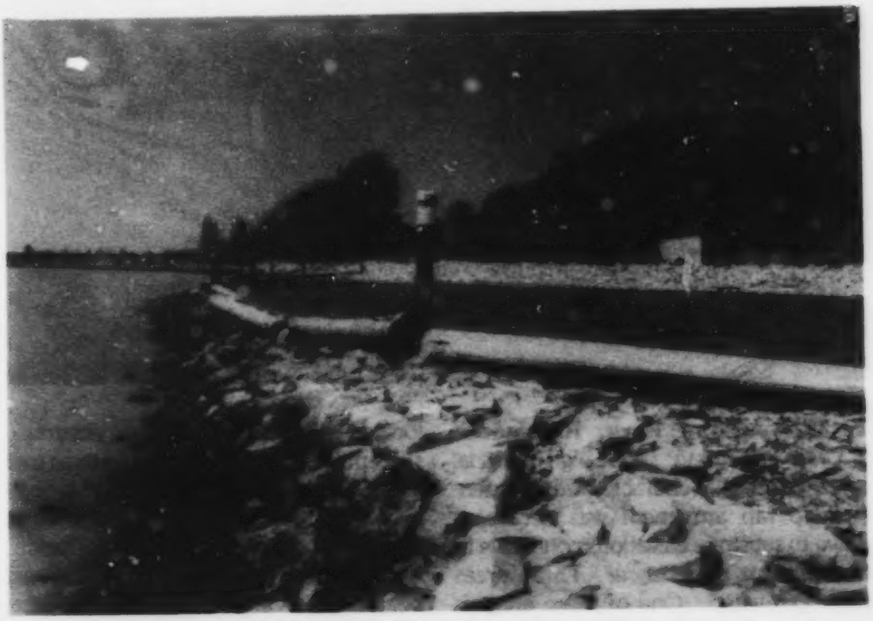

Figure 21.4 A rock berm-sheer boom at Deering Island, Vancouver, B.C.

Examples of Use

Figure 21.5 This rock berm is too low to prevent passage of woody from accumulating on the site - Richmond Landfill, Richmond, B.C.

Figure 21.6 Timber wall at Fraser River Park, Vancouver, B.C.

Garry Point Park, Richmond, B.C.: In late spring, 1989, high intertidal foreshore habitat characterized by extensive rip rap armament was excavated down to substrate elevations conducive to marsh plant persistence. Three areas were excavated. One of these areas is located within an environment extremely susceptible to boat wake and fetch as well as to extensive accumulations of woody debris. A rock berm was constructed to prevent erosion and debris accumulation. A berm opening was placed at the lowest point of the creation site to facilitate drain-

Examples of Use

age and passage of fish, fish food organisms, and organic matter. Preliminary results indicate that the berm is functioning well to protect marsh vegetation transplanted to the site.

Rock Berm-Sheer Boom

Deering Island, Vancouver, B.C.: During late spring to early winter 1989, 0.34 ha of low intertidal sandflat, immediately downstream of Deering Island in the North Arm of the Fraser River, was enclosed within a large rip rap berm and sheer boom (Figure 21.4). Dredge spoil was placed within the bermed area during October-November 1989. The berm functions solely to retain the dredge spoil. The crest of the berm coincides with substrate elevations. It does not protect the site from erosion and debris accumulation.

During planning, the projected cost of sufficient rip rap material to elevate the berm to the HHWL was prohibitive due to the steep slope of the river bottom at the site. A sheer boom was selected to function as the wave abatement and debris barrier structure. The pilings are located in the centre of the berm with the sheer boom stringer logs attached to these pilings.

Richmond Landfill, Richmond, B.C.: This marsh creation site is situated on the north shore of the Main Arm of the Fraser River. A rock berm and a sheer boom were initially designed as debris barriers. Openings in the berm allows for the passage of fish, fish food organisms, and detritus. This site is an example where the top of the berm is too low to prevent passage of woody debris at high water levels (Figure 21.5). The sheer booms located at the berm openings function as much as a debris collection and retention device as a debris barrier.

Piling and Timber Walls

Fraser River Park, Vancouver, B.C.: Two timber walls were installed at the downstream end of the park in the summer of 1988 (Figure 21.6). The walls function to protect the shoreline and promote accretion while at the same time providing a foundation for two public observation decks.

22 *Transplanting Eelgrass*

Introduction

Eelgrass (Zostera marina) is a marine, grass-like seed plant (Figure 22.1). It is most commonly found rooted in soft, unconsolidated substrates in the low intertidal and subtidal zones of protected coastal areas. In addition to providing spawning and rearing habitat for commercially important fish and crustacean species, eelgrass traps and stabilizes sediments which in turn enhances the potential for the establishment of a diverse benthic community.

One of the most important sources of carbon for primary and secondary consumers in shallow coastal habitats originates from within eelgrass communities. Most of this production is channelled through the detrital food web. Creating eelgrass meadows increases the regional detrital contribution into local food chains.

This chapter presents criteria and techniques associated with eelgrass transplants along the coast of British Columbia. Key physical and biological parameters that contribute to plant persistence are presented. Harvesting and planting are also discussed.

Eelgrass transplanting is still considered experimental. Monitoring is presently being performed to evaluate the merits of transplanting techniques and the relative success of transplanting techniques.

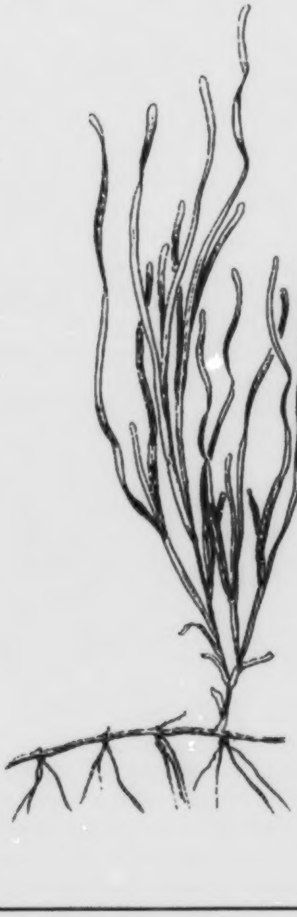

***Figure 22.1** Eelgrass (Zostera marina).*

Application

Before commencing any project involving the manipulation of intertidal and/or subtidal habitats, contact the Department of Fisheries and Oceans or B.C. Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to be consulted regarding the proposed project (Chapter 2).

Most eelgrass transplant opportunities are associated with habitat enhancement/creation programs that include the physical manipulation of substrate elevations (e.g. bottom dredging or dredge material placement). Enhancement opportunities on existing habitats without elevation manipulation are rare. Most habitats conducive to eelgrass establishment and persistence already support the plant.

When possible, conduct small-scale experiments to evaluate the suitability of a proposed transplant site. This will allow for the identification of physical characteristics that may compromise the success of a full-scale transplant.

Design and Installation Guidelines

Physical Criteria

The following physical criteria should be met before a transplant is attempted:

Elevation: MLLW to - 6.5 m

Tidal Current: 0.00 to 1.50 m/s

Salinity: 20 to 30 parts per thousand

Substrate: mud/silt or a combination of mud/silt and sand

Light Regime: light extinction coefficient: 0.085 - 0.600. Secchi disk depth: 3.0 - 20.0 m

The elevation range varies between different sites as a result of other physical variables present and the degree to which they are expressed. The factor limiting the upper intertidal distribution of eelgrass is desiccation. This varies between sites as a result of site specific substrate types. For example, the upper limit of eelgrass will be higher at those sites that possess muddy soils as opposed to sites characterized by coarser substrates such as sand. Mud retains water far better than sand and tends to promote ponding. Eelgrass will be found in areas which retain water as these habitats prevent desiccation of the plant at low tide.

The lower limit of eelgrass depends on a number of interrelated variables that include the availability of suitable substrate, current velocity, light penetration, wave exposure, and turbidity.

Light penetration influences the viability as well as the lower distribution of the plants. Optimum levels for growth during the growing season occur where about 50 percent of the maximum surface incident light occurs. The lower limit of growth in the subtidal environment is reached at that depth where approximately 10 percent of the maximum surface incident light occurs. Field reconnaissance performed over a period of one year may be required to determine the light penetration environment of a proposed transplant site. It may, however, be easier and more cost efficient to survey the elevations of existing eelgrass meadows in areas adjacent to the proposed transplant site.

The environmental factors that prevent the existence of eelgrass at the proposed transplant recipient site must be identified. The lack of vegetation may be due to inappropriate elevations or un-

Design and Installation Guidelines

suitable substrates. Other physical parameters may also be involved. Seasonal turbidity, currents and erosion that may not be evident during the initial site assessment may account for plant absence. Some past disturbance may have destroyed plants that once existed at the site (e.g. log storage or effluent discharges). Identification of such disturbances and subsequent remedial measures to prevent their recurrence are prerequisites for project success.

Before designating an intertidal or subtidal habitat for eelgrass habitat creation, consider the functional contribution of that habitat to the local ecosystem. For example, bare regions that exist within an eelgrass meadow may add to the diversity of the local animal and plant community. Planting these open areas may have a net negative effect on meadow diversity and productivity. Assessment of these open habitats within each individual eelgrass meadow should be performed in order to determine the net effect an eelgrass transplant program might have on local ecosystem functions.

Harvesting and Storing Plants

Eelgrass transplant material obtained from a high current regime exhibits superior growth rates. Higher rhizome mat integrity, characteristic of plants from such an energy environment, improves collection efficiency.

A high current area is defined as an area where surface current velocity exceeds 0.50 m/s. These areas are characterized by discrete, raised patches of grass on sandy substrate with a low concentration of organic matter.

Several techniques exist for the harvest of transplant material based on the type of vegetative propagule that is used.

Sods

- a shovel is inserted at least 20 cm into the substrate, ensuring that as much of the root-rhizome complex is included as possible

- sods may vary in size; size selection should consider ease of manipulation and transport as well as plant quality and shoot density

- the sods should be shaken free of attached sediment at the harvest site; care should be taken to maintain the integrity of the rhizomes in order to maximize planting success

Plugs

- plugs are cores of plant material and associated sediment approximately 10 cm in diameter and 15-20 cm in depth; they are obtained with a cylindrical coring device constructed of PVC pipe or other similar coring device that will not damage the shoot

Sprigs

- sprigs consist of a single rhizome with 3 to 4 leafy shoots; they are obtained with a shovel or spade inserted at least 20 cm into the substrate

- the sprigs are shaken free of attached sediment taking care to keep the root-rhizome system intact

In order to maximize plant survival, plant material accustomed to the specific physical and biological conditions of the transplant site should be used. Plant material obtained from nearby eelgrass meadows is recommended.

It is preferable to harvest only that amount that can be planted in the same work day. If the transplant program necessitates the storage of plants, sediment free sods or sprigs may be stored either in

Design and Installation Guidelines

ambient seawater or out of water wrapped in wet canvas, burlap, or seaweed (Ulva). It is important to avoid anaerobic conditions during storage, as this will lead to plant cell death and decreased viability of the propagules.

The danger of anaerobic conditions developing during storage is especially pronounced with plugs. Sediments associated with plugs are prime habitat for bacteria. Bacterial respiration quickly utilizes oxygen dissolved in the interstitial water of the sediment/rhizome plug. Plugs should be planted the same day of harvest.

Care must also be taken not to expose plants to direct sunlight. High temperatures and desiccation result in plant tissue death.

Eelgrass, being aquatic, lacks the supportive tissues that are typical of emergent marsh plants. This makes eelgrass more susceptible to handling damage. Care must be taken when handling eelgrass during transplant efforts.

Planting

Sods, Sprigs

- sods may be planted intact or divided into smaller planting units

- in low energy environments anchors may not be required; the planting units are placed in the sediment ensuring the root-rhizome system is buried, smaller sods and sprigs should be planted by digging a small hole in the substrate (8 cm deep) with a trowel, placing the plant unit into the hole, and covering it with the substrate

- in high energy environments anchors are necessary for the root-rhizome system to become firmly established

Several types of anchors may be used to secure plant material (Figure 22.2). Construction rods (rebar), metal mesh, coat hangers, and nails have all been used to anchor plant material (Figure 22.3). Eelgrass appears to be unaffected by metal anchors.

When using rebar, each rhizome is tied to a rebar anchor using string or elastic bands. Rebar of varying lengths and diameters may be used according to the local energy environment. It is essential that the rhizome-root complex be buried. The rebar may require additional anchoring with the use of large nails (spikes, 23 cm).

Shoots can be pulled in clumps from dug-up mats and held upright to facilitate attachment of metal coat hanger anchors (approximately 15 shoots per planting unit). Approximately one third of a coat hanger is pre-cut and bent into an L-shape. Shoots are wrapped with a piece of bonded construction paper and attached to the coat hanger with a twist-tie or elastic fastener (Figure 22.3). Inserting the plants into the sediment so that the top of the L-shaped anchor is covered with sediment.

Metal meshes used in the construction industry for structural rigidity in cement floor structures may be used to anchor sprigs. This form of anchorage has the advantage of having distinct unit squares from which a planting grid may be established. Sprigs are attached to the mesh by string, twist tie or elastic fastener.

The EZ-fabric netting should be cut into 20 cm X 20 cm squares and woven with 15 eelgrass shoots. The rhizomes are exposed on the underside of the square. The square is then pinned to the substrate surface using spikes.

EZ-fabric squares may be used to attach plant units. EZ-fabric is a combination of propylene yarn interwoven with biodegradable paper strips that is lighter, easier to handle, and less expensive than most of its metal counterparts.

Design and Installation Guidelines

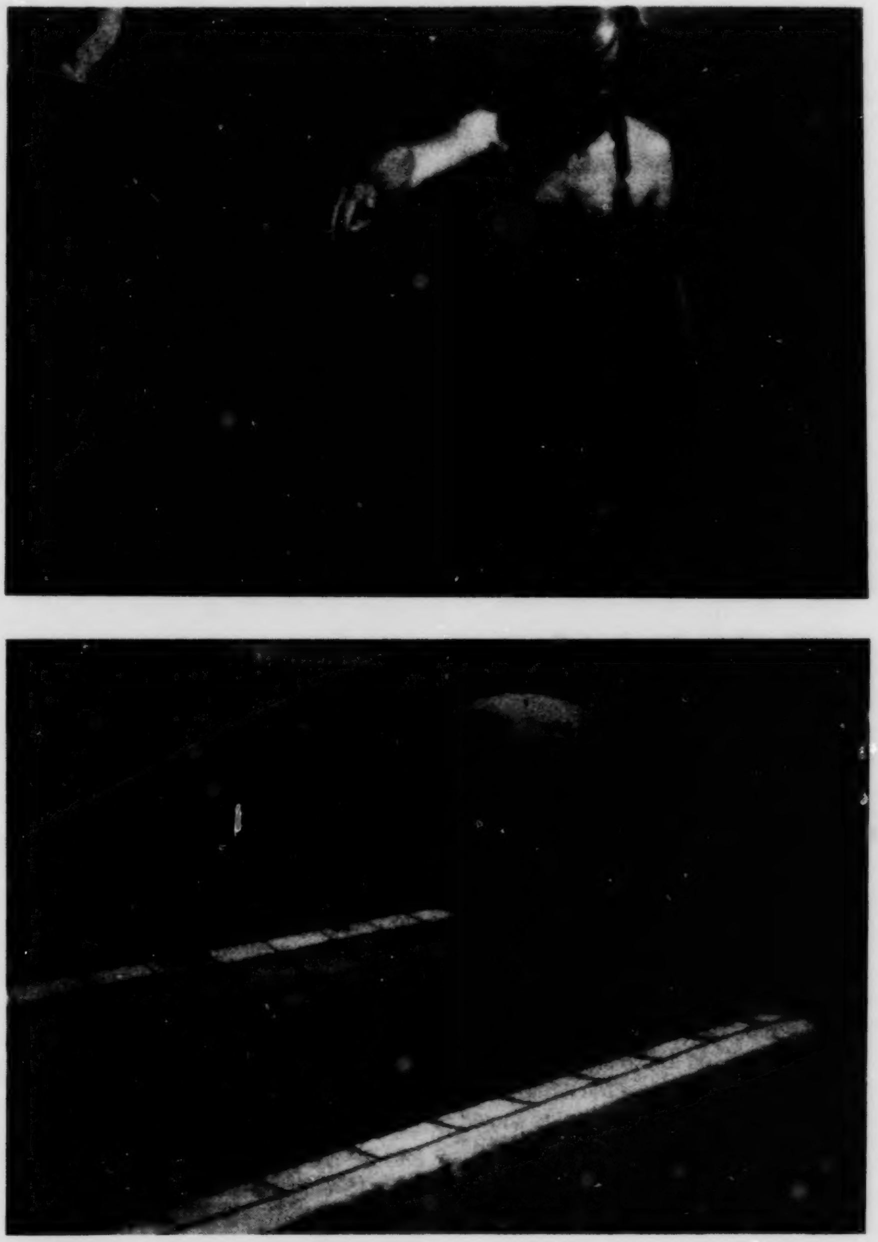

Figure 22.2 Eelgrass anchoring devices: rebar (top); iron mesh (bottom)

Preparation of plant material is performed in the field out of the water. Plant collection, washing them free of sediments, and anchorage may be done in the water. Some collection and planting may be performed wading through the low intertidal and high subtidal zones at low tide. Subtidal collection and planting may be performed using divers. The greatest difficulty with diver subtidal planting is the limited visibility resulting from sediment clouds created by the divers as they plant the material.

Design and Installation Guidelines

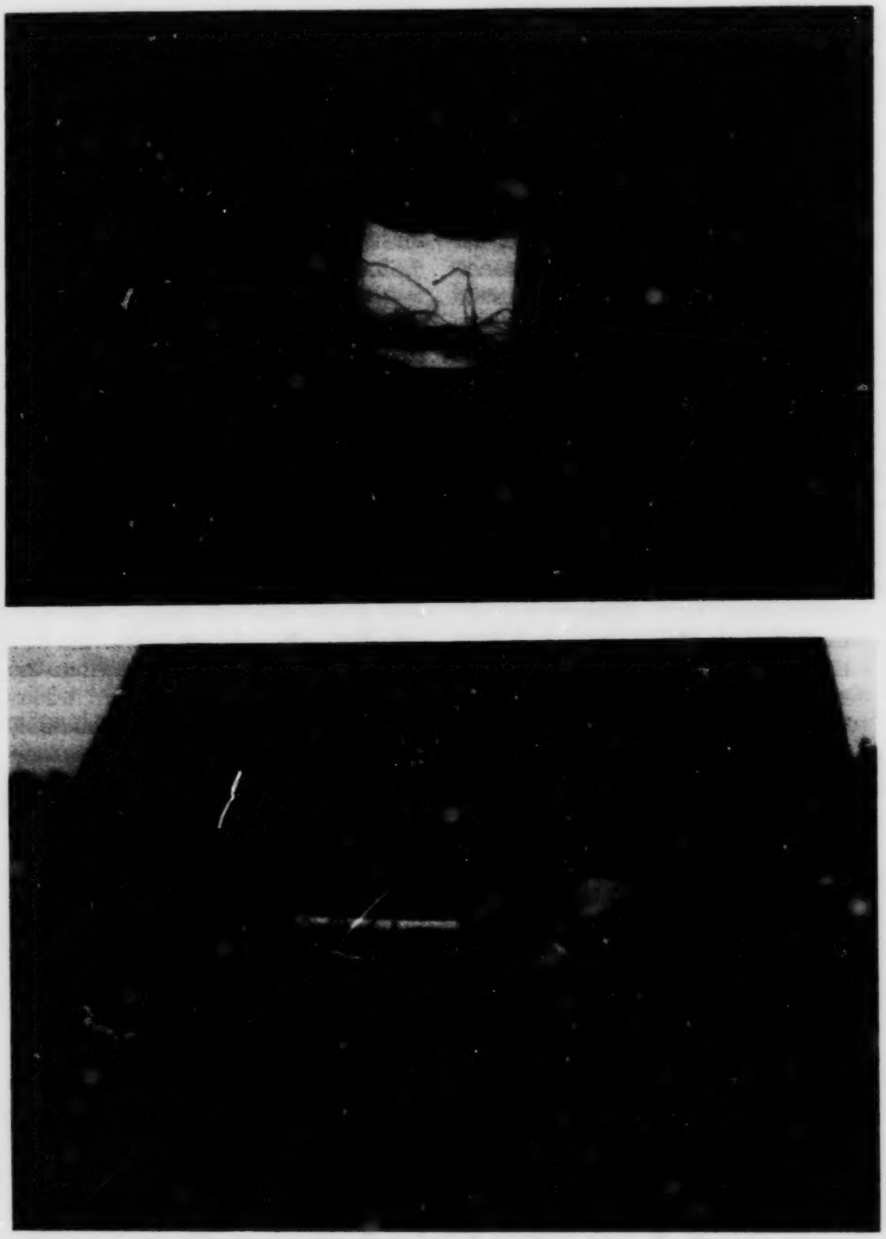

***Figure 22.3** Fastening eelgrass to coat hanger anchor: wrapping banded construction paper around sprig (top); and, tying to anchor (bottom)*

Plugs

Plugs are obtained from the donor site during low tide when eelgrass is easily accessible. The coring devices used for plug extraction can also be used to excavate recipient holes for individual plugs.

Planting Densities

The density at which plant material is planted depends on several factors. If it is the intent of the project to replicate as soon as possible the densities exhibited in the donor site, a high planting density will

Design and Installation Guidelines

reflect this objective. However, it may be more cost effective to plant at lower densities as fewer plants would be required. Expansion of roots and rhizomes in the areas between plant units will occur. Low density transplant recipient sites, though taking longer than high density transplants to establish continuous cover, should approach plant densities typical of the donor site if appropriate physical conditions are present. Three factors must be considered when selecting planting densities:

- at higher densities leaves may become entangled creating a mass that is more susceptible to being dragged away by currents;
- at lower densities the space between the plugs may create a physical environment that promotes the establishment of tidal channels at low tide, in turn resulting in the erosion of isolated clumps;
- high density transplants require larger donor sites than do low density transplants, hence, the impact will be greater on donor meadows with high density transplants

Eelgrass transplants involving coat hanger anchors should use a 0.80 m^2 grid in low current areas (not exceeding 0.50 m/s) and a 0.70 m X 0.55 m grid in high current areas. As eelgrass tends to propagate in the direction of the least resistance, the down current spacings in the high current areas should incorporate the longer grid dimension.

Preferred densities for rebar transplants range from 10-13 shoots per square meter. Un-anchored sprigs have been planted at 12-13 per square meter. Care must be taken to extract plant material that will successfully recolonize the donor site.

Diving is preferred to wading as a means of transplanting in an intertidal area where visibility is good and lead lines with grid boundaries and interval markers can be used. Divers should perform the planting while facing into the current flow. Care must be taken to ensure that newly planted material is not uprooted.

Maintenance

There is little to be done to significantly increase propagule survival if extensive plant death occurs. Rather than attempt to apply some short term remedial measure, it would be best to identify and quantify the environmental factors responsible for project failure. The information obtained could be applied to future transplants.

Factors Influencing Cost

Cost estimates for a transplant program should consider the time of year when the work is to be performed, recipient site area, materials, and equipment required.

The most cost effective propagule for use in transplant projects is the individual sprig. Sprigs require less preparation than rebar, coat hanger, spike, EZ-fabric, metal mesh, and sod plant units. Sprigs

Factors Influencing Cost

also require less equipment and materials than all the planting units discussed with the exception of sods because they require storage and are more expensive to transport due to their weight and size.

When considering program cost, it is more appropriate to consider cost per shoot and projected areal coverage. Some planting strategies initially cost less than others. Evaluation of the site several growing seasons after planting will reveal the degree of vegetative expansion. These long term results may significantly affect the final cost per shoot ratio.

A typical situation where one type of transplant may initially cost more than another, yet in the final evaluation be less expensive, is when comparison is made between sods and single shoot sprigs. The sods require relatively little preparation time. Large spikes are used for anchorage. Single shoot sprigs require a substantial investment of time for separation of sprigs from sod, individual anchor attachment, and planting. Sods, on a cost per shoot ratio, initially are less expensive than sprigs, however, the potential for vegetative expansion differs between the two propagules. Each sod unit has only a limited perimeter from which to expand. Single shoot sprigs can initially expand in any direction without restriction. Both transplant techniques may initially establish 1000 shoots, but the sprig technique will eventually result in a greater number of shoots established and greater areal coverage.

The time of year of transplant also influences cost. Transplant programs in late winter or early spring often involve field work during inclement weather and at night when the lowest tides occur. This, however, is the time of year when the greatest success of plant establishment can be realized. The plants suffer minimal physiological shock due to a state of dormancy.

Field work is less costly during summer when, with daytime low tides and favourable weather, visibility is unrestricted and more work can be accomplished for a given amount of time. The plant is, however, most susceptible during summer to physiological shock because of the increased likelihood of direct exposure to sunlight and high temperatures. The eelgrass also has a reduced ability to recover from physiological shock as its energy reserves in its rhizomes have already been expended for growth during the peak growing periods of spring and early summer.

Accessibility to the transplant and donor sites influences cost. A successful strategy incorporates the harvest of donor material at low tide, transport of the material to the recipient site at the following high tide, and planting of the material via wading at the next low tide. For diver planting, the placement of plant units would preferably occur at the high tide following the low tide at which harvest was performed.

Considerations of working conditions and how they affect project cost, and not the seasonal biology of the plants, may be the influential factor affecting the decision as to the time of year to perform the transplant. Precise information regarding optimal transplanting periods is presently still being collected and long term cost benefits of late winter/early spring transplants versus summer transplants is still in question.

Advantages of Technique(s)

Extensive evaluation of the different propagules and associated techniques has not been performed on the west coast. Therefore, the general advantages of all the techniques as a whole are presented below.

- no need for large machinery or specialized equipment
- material costs are typically low
- technically very simple (excluding scuba diving), no exceptional engineering expertise is required

Disadvantages of Technique(s)

The general disadvantages of eelgrass transplant techniques are:

- harvesting, plant preparation and transplanting is labour intensive
- qualified scuba divers are required for some planting strategies
- the risk of failure is high; typically, very little information is available on annual trends in physical and biological parameters of specific sites; site selection is usually based on a limited set of observations that in turn may not be indicative of typical conditions at the site and may lead to project failure due to undetected or unforecasted parameters and events

Examples of Use

In addition to this manual's presentation of examples of use within our region, a summary of projects for the Pacific northwest is presented in Table 22.1.

Roberts Bank, Delta, B.C.: During the expansion of the Roberts Bank Superport in 1981-1983, eelgrass was transplanted to two sites adjacent to existing vegetation and the superport jetty (Harrison 1984). Both sites satisfied the basic criteria for eelgrass transplants as outlined by Fonseca et al. (1982). The transplants were monitored for 5 years.

Several techniques were employed. These included un-anchored shoots, shoots attached to lengths of reinforcing rod, and plugs. Technique modifications included different planting densities, lengths of rhizomes, current velocities and fertilizer treatments.

A substantial number of plants have survived and many of these have expanded rapidly during the spring and summer growing seasons. Success of the transplant material depended on site elevation. Eelgrass survived where the leaves were continually immersed in water.

Hidden Harbour, Vancouver Island, B.C.: The Hidden Harbour boat basin, located 1 kilometre south of Campbell River, B.C., was dredged in 1985. Eelgrass was transplanted to the site in 1987. The basin is sheltered and possesses suitable water depth and substrate for eelgrass.

Approximately 4,000 eelgrass shoots were individually planted by SCUBA divers in a 1,900 square meter area. Boat floats were placed over the transplant sites 5 months after transplant. The floats partially shade the transplant area.

Examples of Use

Preliminary observations in March, 1988, revealed both low shoot survival (28%) and a substantial decrease (23%) in transplanted area. It appears the light regime under the boat floats provides an environment that will sustain only a sparse eelgrass meadow. Shading appears to prevent the establishment of dense vegetation.

Gibsons' Harbour, Gibsons, B.C.: Eelgrass was transplanted in 1985 onto dredge spoil adjacent to a breakwater at Gibson's Harbour, B.C. Dredge spoil was used to raise the sea floor to 2 meters below chart datum. This created a water depth environment suitable for eelgrass. The dredge spoil was composed of gravel and cobble and only a few areas possessed an appreciable amount of sand or mud. The surface of the dredge spoil also exhibited an irregular topography with few flat areas for planting.

SCUBA divers performed the transplant. Techniques used included unanchored shoots, shoots tied to pieces of reinforcing rod, shoots with sediment in peat pots, and shoots tied to pieces of wire mesh. The only plots that were successful were those located in an area where fine sand had been deposited. The project emphasized the importance of the type of substrate required for successful eelgrass transplants.

TABLE 22.1 SUMMARY OF EELGRASS TRANSPLANT PROJECTS IN THE PACIFIC NORTHWEST (from Thom 1989)

Abbreviations:

D - Date(s);
H - Habitat;
A - Approx. Area;
T - Technique;
D - Density of Plantings;
S - Success of Plantings;
C - Conclusions.

Gibsons Harbour, B.C.

D - May 1985;
H - gravel, cobble, little sand or mud, subtidal;
A - ;
T - a) unanchored shoots b) shoots tied to pieces of reinforcing rod c) shoots with sediment in peat pots d) shoots tied to pieces of wire mesh;
D - ;
S - low in gravel and cobble; moderate in fine sand and mud;
C - substrate is critical; water clarity is critical.

Hidden Harbour Marina, B.C.

D - April 1987;
H - mud, subtidal;
A - 1,900 m^2;
T - shoots;
D - approx. 2/m^2;
S - 28% shoot survival, 23% decrease in transplanted area;
C - eelgrass can survive in marina, but lush vegetation should not be expected where plants are shaded.

Roberts Bank, B.C.

D - 1981-1983;
H - intertidal and subtidal;
A - ;
T - a) unanchored shoots b) shoots attached to lengths of reinforcing rod c) plugs;
D - ;
S - good in most areas;
C - eelgrass survived best in areas with standing water at low tide.

Blaine Marina, WA

D - 1987;
H - intertidal sand/mud;
A - ;
T - ;
D - 10 cm diameter plugs at 1 m spacings; approx. 10 shoots per plug;
S - up to 100% survival of shoots in pots; 20% survival of shoots in plots;
C - donor plots recover rapidly; potted shoots survive well.

page 214

Examples of Use

TABLE 22.1 SUMMARY OF EELGRASS TRANSPLANT PROJECTS IN THE PACIFIC NORTHWEST cont.

Dakota Creek, WA

D - Spring 1988;
H - intertidal (+0.5 to +1.0 m MLLW);
A - approx. 60m^2;
T - shoots;
D - 1 shoot per 0.3 m space;
S - 80% survival at lowest elevations, <30% survival at higher elevations;
C - coarse substrate, high elevation of tide flat and disturbance by boats affected survival.

Sequim Bay, WA

D - 1985;
H - intertidal sand/mud;
A - 8,000 m^2;
T - a) shoot bundles b) plugs c) shoots;
D - 1 unit at 0.75 m spacing; 11,00 shoots planted;
S - 800 m^2 of bed remains after 5 years; very dense in surviving area; total shoot abundance = 200,000;
C - planting methods gave similar results, finer substrate and deeper areas with standing water had greatest survival.

Bangor, WA

D - 1987;
H - intertidal and subtidal sand;
A - 46 m^2 (total of 5 plots);
T - ;
D - ;
S - 4 of 5 plots died, remaining plot is subtidal;
C - steep slope of intertidal area (where planted) may cause losses.

Anderson Pt., Battle Pt., Manchester, WA

D - 1977;
H - eelgrass beds;
A - ;
T - several 1 m^2 plots per site; a) 20 cm diameter plugs b) unanchored shoots c) anchored shoots;
D - ;
S - good survival;
C - all techniques have a good chance of success if proper habitat is selected.

Smith Cove, WA

D - 1987-1988;
H - intertidal sand/mud;
A - 230 m^2;
T - plugs;
D - 0.5 m spacing;
S - no survival by March 1989;
C - drifting sand and silt covered the plots.

Magnolia Bluff, WA

D - 1988;
H - +0.1 to +0.5 m MLLW;
A - 260 m^2;
T - ;
D - ;
P - no survival by April 1989 – drifting sediment covered plots;
C - .

Puget Sound, WA

D - 1974;
H - intertidal and subtidal;
A - various plots – 0.1-1.5 m^2;
T - a) plugs b) anchored shoots c) unanchored shoots; up to 500 m^2;
S - 25-100% cover;
C - small plots placed in appropriate habitat do well, disturbance by waves reduces survival, all techniques work well, long term success of large-scale projects unproven.

Siuslaw River, OR

D - 1976-1977;
H - intertidal sand, swift tide currents;
A - 290 m^2;
T - shoots (3 per hole at 0.15 m spacing);
D - approx. 133/m^2;
S - 90% survival;
C - low fencing around plots reduced flows and improved survival, standing water at low tide over plots increased survival

Humboldt Bay, CA

D - 1982;
H -0.75 to +0.75 m MLLW;
A - ;
T - shoots in rows of elevation range;
D - ;
S - good survival in first several months, severe storms destroyed plots;
C - transplanting success is enhanced if below-ground production of shoots is good.

Examples of Use

TABLE 22.1 SUMMARY OF EELGRASS TRANSPLANT PROJECTS IN THE PACIFIC NORTHWEST cont.

Bodega Harbor, CA

D - Nov. – April 1984;
H - shallow subtidal flat and channel bank;
A - 11,000 m^2;
T - shoot bundles;
D - 1 bundle per 0.65-0.8 m;
S - 40% survival and 90% cover on tidal flat, 5% survival and 10% cover on channel banks;
C - low current, low disturbance, low turbidity areas did best.

Richmond Harbour, San Fransisco Bay, CA

D - April 1985;
H - intertidal sand/mud in eelgrass beds;
A - 9 m long linear plots;
T - shoot bundles;
D - 1 bundle per 1 m;
S - approx. 100% mortality by end of study;
C - mature transplants did the best, handling shock may contribute to losses.

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23 *Artificial Reef Creation*

Introduction

Artificial reefs are an effective fishery enhancement tool in marine waters. They increase local productivity and harvest of selected finfish and shellfish, and create additional recreational fishing opportunities for both boat and shore based angling.

An artificial reef enhances fish aggregation and production habitat required by various invertebrates and fishes. A reef provides hard substrate essential for the successful colonization of encrusting organisms such as plumose anemones, barnacles, mussels, hydroids, corals, and algae. The increased habitat complexity and heterogeneity of habitats created by the artificial reefs (and the colonizing organisms themselves) provide a multitude of microhabitats for many invertebrates. These in turn provide food for fishes and many invertebrates. The reef also provides shelter for many fishes and motile invertebrates such as shrimp and crabs. Some fish species use the irregular profile of an artificial reef for orientation to nearby feeding grounds.

The purpose of this chapter is to provide planning details and construction guidelines for the creation of an artificial reef. It concentrates on the biophysical prerequisites for the enhancement of **rough bottom fisheries**.

Application

Before commencing any project involving the manipulation of intertidal and/or subtidal habitats, contact the Department of Fisheries and Oceans or Fish and Wildlife Branch office in your area. A representative from either office will identify the regulatory agencies that will have to consulted regarding the proposed project (Chapter 2).

Qualified engineers and biologists should be consulted during both the planning and implementation stages of the project. Site specific biological and physical parameters will determine the suitability of the site for reef construction.

Most artificial reefs constructed on the west coast have been established in order to enhance the local recreational fishery. Reefs can also constructed to enhance local commercial fisheries.

Design and Installation Guidelines

Artificial Reef Site Selection

Depth of Water

The depth selected for an artificial reef is dependent upon navigational clearance, material stability and the type of fishery to be enhanced.

With non-fishing wharf reefs, the highest part of a reef should be of sufficient depth to allow unimpeded navigation. At sites with a depth greater than 20 meters below mean low water, reefs should have a minimum clearance of 15 meters. In those areas exhibiting depths less than 20 meters, a general rule is to allow clearance equal to the greatest draft of ships travelling through the area.

Design and Installation Guidelines

Fishing wharf reefs usually exclude commercial and recreational boating from the area. The depth of the reef should correspond to the depths inhabited by fish species targetted for enhancement.

Current and Wave Activity

One of the greatest contributing factors to reef damage or loss is due to wave action and currents. Strong currents and wave action can scatter materials, cover the reef with shifting sediments, and compromise the structural integrity of more complex reef designs.

Water particles in wind driven waves move in circles. These particle circles decrease as the depth of the water increases . The motion becomes negligible at 1/2 the wavelength. For site selection purposes, the average length of stormwaves in a specific area must be known in order to predict the potential damage that wave action will cause at a particular depth.

For fishing reefs, artificial structures should be constructed perpendicular to prevailing currents to allow the maximum number of fishermen to anchor and fish the reef.

Reef construction in areas of strong currents and very shallow depths should be avoided. Federal and Provincial agency oceanographers and marine geologists should be consulted for information about currents and wave action that may be encountered at the proposed artificial reef site.

Sedimentation

Coastal environments near estuaries experience substantial sediment loading. Water velocities drop suddenly allowing particles of clay and silt to settle out. Settlement of these particles on an artificial reef can decrease the potential of a reef to support a rich invertebrate community.

Small crevices and holes that provide habitat for small fish and invertebrates are smothered by falling sediment. Sediment clogs the filtering structures of small filter feeding organisms. Colonization by encrusting organisms is inhibited by sediment ladened surfaces.

Examination of charts and site reconnaissance will help avoid locations with high rates of sedimentation.

Water Quality

The proximity of the site to domestic and industrial sewage outfalls is an important consideration. Organic solids have much the same physical impacts as natural sediments. The decomposition of organics places a substantial demand on dissolved oxygen, often to a point where marine life can no longer be supported. Toxins contained within domestic and industrial effluents can have sublethal and lethal effects on marine organisms. Sublethal effects include impaired reproduction and physical development (e.g. development of lesions and tumours).

Locations of sewage outfalls can be obtained from the Waste Management Branch of the B.C. Ministry of Environment and the Environmental Protection Service of Environment Canada.

Bottom Type

The ocean bottom type will determine the longevity of the reef. The bottom type is classified according to sediment size . Sediment particles are divided into several different size ranges based on their average diameter. The most common sediment particles found in coastal waters are clay, silt, and sand.

A bottom composed of un-consolidated clay particles will not support low density reef materials whereas a bottom composed of compact sand particles is suitable. The ideal bottom is bedrock with little sediment cover.

Design and Installation Guidelines

The mobility of substrate at a particular site must also be addressed. Moving substrate will smother sections of the reef, filling small crevices and holes which are vital habitats for organisms that comprise the lower levels of a reef food chain.

A single survey of a site to determine reef suitability often will not indicate whether substrates are susceptible to mass movement. Seasonal surveys are necessary to determine the sediment regime of a particular site.

Existing Bottom Profile And Structures

Existing structures can compose part of an artificial reef. Old vessel wrecks, bedrock outcroppings and man-made structures such as rock jetties can be incorporated into a reef design. These structures and bottom features increase habitat complexity and usually indicate solid bottom composition conducive to reef persistence.

Fishery Incompatibility

The proximity of a proposed reef to existing nursery habitats of important fishery species should be determined. Attracting adult reef and **pelagic** fishes may significantly increase juvenile mortality of other species. Existing nursery habitats, such as those typical of estuarine environments, should be located and mapped with reference to the proposed reef location. Sampling in the general vicinity of the proposed reef site should be performed to determine seasonal fish species utilization.

Conflict of Interest

The interests of other groups using potential reef locations must be considered. Commercial and recreational boat traffic must also be considered in the planning process. A reef placed near a heavily used area must be well marked. Always consult user groups when selecting a site.

Reef Construction Units and Materials

Tires

Scrap tires are readily available from tire dealerships and can be readily assembled into many designs. Tires are inert and can be transported easily. In addition to providing a large surface area for encrusting organisms, they also provide suitable habitat for many invertebrates and fishes.

Tires usually have to be ventilated and ballasted to prevent movement off the reef. Ventilation allows trapped air to escape from the tire. This decreases buoyancy which in turn increases stability of the tire unit. Knives, chisels, axes, drills, guns and blow torches can be used to ventilate small tire reefs, however, manual and pneumatic punches and a baler are generally required to ventilate larger tire reef complexes. Ballasting adds stability and is accomplished by adding weight to the tire unit. The added weight offsets the natural buoyancy of the tire.

Tires may be assembled into a variety of unit types, a number of which are presented in Figure 23.1 and discussed below.

Single Tire Unit

A No.10 can (737 g coffee can) filled with concrete inserted into the interior of a car tire acts as a ballast. Vent(s) created in the tread portion of the car tire opposite the ballast allows air trapped inside to escape. The single tire unit may be attached to the reef or used as part of a more complex design.

Triangle Unit

Three single tire units are secured with polypropylene line. The tread of all three tires touch the ground when standing upright.

Design and Installation Guidelines

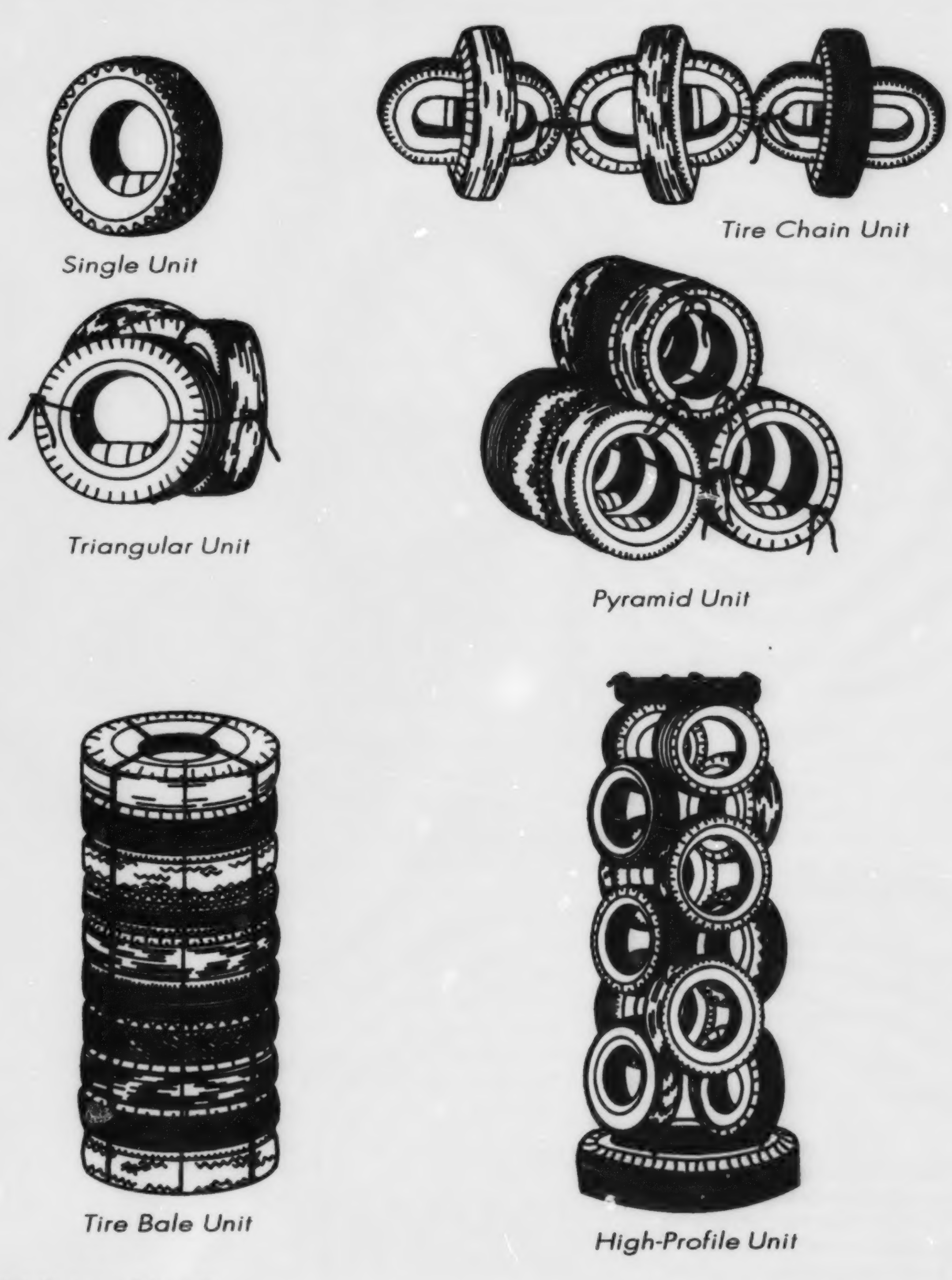
Single Unit
Tire Chain Unit
Triangular Unit
Pyramid Unit
Tire Bale Unit
High-Profile Unit

Figure 23.1 *Six types of tire units.*

Design and Installation Guidelines

Tire Chain Unit

To create a tire chain unit, a folded tire is inserted through the centre of a one-tire unit. Holes are drilled, punctured, or slashed through the inserted tire to allow trapped air to escape. Sections are joined together by polypropylene line. Where units are tied together to form a pyramid-like or other more complex structures, concrete-filled tires are used for additional anchorage.

Pyramid Tire Unit

A cylindrical assembly is created by attaching three single tire units together with treads touching the ground. Two such assemblies are bound together to form the base of the pyramid. An additional cylindrical assembly is created using three unballasted car tires. The upper sections of the two outside tires are vented to allow release trapped air. Trapped air in the middle tire ensures that the pyramid tire unit will sink to the bottom in an upright position.

High-Profile Tire Unit

To create this tire unit, a truck tire is first placed horizontally on flat ground. The tire is divided into quarters into each of which a large hole is drilled, punctured, or slashed. Four 3 meter reinforcing rods are bent at a right angle 70 centimetres from one end. The bent ends of the rods are placed through the holes in the tire. The rods may be attached with wire or welded together at the centre of the tire. The truck tire is then filled with concrete. A single truck tire with four vertical rods comprises the base unit.

The base unit anchors successive layers of car tires. The tires are punctured, slashed or drilled to accommodate the support rods. Two tires are forced down the reinforcing rods parallel to each other. Successive tires are pushed down the rods at right angles to the tires below. The lower tires are ventilated to ensure the structure remains upright and to decrease buoyancy of the unit. A horizontal car tire is used to cap the structure. The tips of the rods are bent to hold the tires in place.

As reinforcing rods tend to corrode, a line or band of non-corrosive material such as plastic should be used to tie the car tires to each other and to the base unit. The main line or band should be inserted through the base tire before the concrete is poured. This precautionary measure will ensure long term structural integrity of the unit.

Tire Bale Unit

This tire unit is constructed with a tire baler. It is composed of 5 to 12 ventilated car tires compressed into a bale. The tires are secured to each other with 2 or 3 metal bands and 2 or 3 plastic bands or polypropylene lines which hold the tires together once the metal bands corrode and break. The metal bands are used initially as they tend to maintain the compressed tires together better than the more flexible plastic bands and polypropylene line. Each unit can be weighted with concrete directly or tied by cable or chain to a large concrete weight. The units may be stacked or strung together to form more complex units.

Rock and Concrete Debris

Rock and concrete debris are excellent physical habitat components (Figure 23.2). These materials will last indefinitely. The porous nature of concrete surfaces encourages the attachment of encrusting organisms. Rock also has a more natural appearance.

Concrete Culverts

Stacked concrete culverts and pipes provide ideal habitat for larger **demersal** fishes. They may be obtained from municipal and city engineering departments or highways contractors. Culvert rejects may be obtained from concrete product

Design and Installation Guidelines

companies free or purchased for a modest price.

Concrete Sidewalk and Foundation Debris

There is no shortage of sidewalk or building foundation debris. Some municipalities, cities and demolition companies may pay for disposal of material. It is best to have a wide range of debris sizes. This prevents stacking of similar sized slabs of material and ensures the creation of crevices and small openings.

Bricks

Bricks are easily obtainable. Reefs composed of this material will provide more habitat for smaller fish than most other reef materials. They are ideal when used with large concrete slabs. The bricks prevent the slabs from stacking on each other, thereby increasing **interstitial** habitat.

Rock

Stacked angular boulders creates excellent habitat complexity. The rock blends in well with the surrounding natural environment. This is a consideration if the artificial reef is also designated for recreational SCUBA diving. Rock may be obtained from gravel pits and highway construction sites.

Vessels

Old ships and barges may be used as new reef material and as effective additions to existing reefs. The high profile afforded by vessels produces upwellings and eddy currents that attract schools of small fish which in turn attract pelagic predators.

Holes of sufficient size must exist in the vessel to allow free passage of currents and fish in and out of the vessel.

Wooden vessels should be avoided. They are difficult to sink and maintain in place. They are susceptible to marine borers and collapse rapidly from the effect of wave action.

Care must be taken to remove all structures and components that may foul the environment. Motors and propulsion equipment should be removed, as should all other parts that contain lubricants.

Automobiles

Automobiles should not to be used for artificial reefs. The preparation time needed to remove pollutants such as oil, gas, radiator fluid, and flammables is excessive relative to the time to fabricate and prepare other reef materials. Individual automobile bodies are difficult and expensive to transport and have a very short life in the marine environment (e.g. they corrode in 3 to 6 years). Automobiles are best left in the wreckers yard.

Prefabricated Concrete Structures

Prefabricated concrete structures make excellent reef material. They have the advantage of being able to incorporate designs for specific habitat features required by target species. Construction bricks or precast concrete are used to fabricate these structures.

Placement of Reef Material

Most artificial reef material requires the use of heavy machinery such as a crane, bulldozer, front-end loader, truck and barge for handling and transport. The material is usually end-dumped from a barge at the reef site (Figure 23.3). Placement of material is somewhat haphazard when end-dumping and some allowance for unexpected configurations should be incorporated in the enhancement plan.

Design and Installation Guidelines

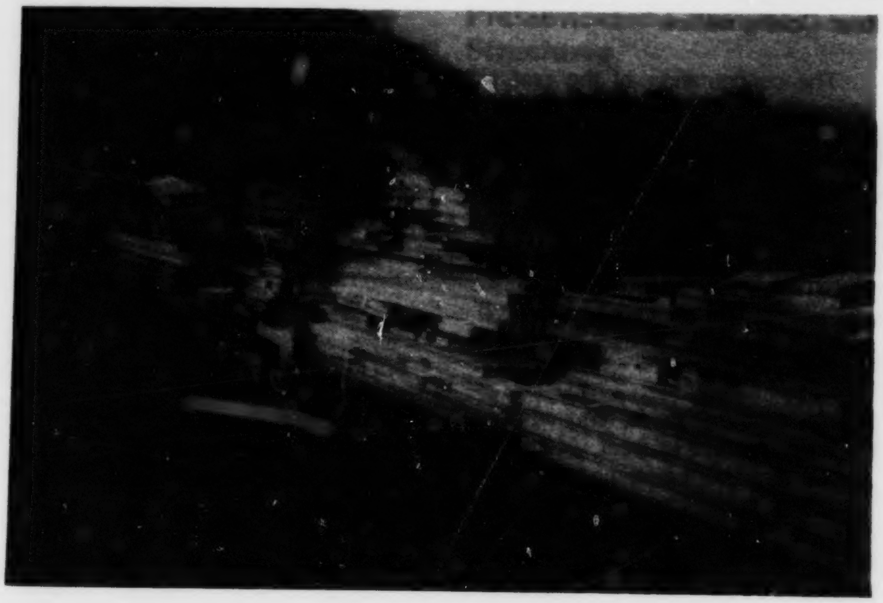

Figure 23.2 *Concrete debris such as old wharf decking, is excellent reef material.*

Figure 23.3 *Reef material is usually end-dumped from a barge at the reef site.*

Ships and barges are towed to the reef site by towboats. The reef barge or vessel is usually loaded with sand or rock and sunk at the reef site using explosives to blow holes in the hull.

Small, simple tire units may be transported to the reef site from marinas by recreational boaters. Arrangements may be made with anglers to transport and place a tire unit at a buoyed reef area as they head out to fishing grounds. One tire unit placed for each fishing excursion soon results in a significant accumulation of reef material at the enhancement site.

Design and Installation Guidelines

Reef Configuration

The configuration of the reef will dictate what type of fish species will be attracted to the site. Low profile reefs attract demersal fish species and macroinvertebrates. High profile reefs will attract pelagic fishes.

Demersal fish stocks will be enhanced by reefs constructed in a circle or square configuration with one benthic opening. The central area within the circle or square should not exceed a width or diameter of 18 meters . Reefs associated with fishing piers should be parallel to the pier to direct pelagic fish species past the pier.

Maintenance

No maintenance is required for a properly constructed reef. Monitoring studies may be performed to assess whether project objectives were met in terms of targetted fish species enhancement. A reef's configuration or relief may be modified by the addition of material to suit the habitat requirements of targetted fishery species. Removal of reef is far more difficult and is usually not a viable option.

In situations where a reef is failing due to poor site selection, it is best to document the project and factors contributing to its failure and abandon further enhancement efforts at the site.

Factors Influencing Cost

The factors that influence the overall cost of an artificial reef project include the price for reef materials, transport of materials to the project site, on-site construction and material placement. Regardless of the reef material used, there is always a substantial effort required by many individuals in the planning and implementation of an artificial reef program.

Advantages of Material Types

Tires

- very low cost material: may be obtained free from tire dealerships good potential to incorporate designs specific to fish and invertebrate species targetted for enhancement
- low cost placement options: tire units may be fabricated and stored at a marina where sport fishermen can carry single units to buoyed reef areas for sinking as they proceed to fishing grounds
- long term reef material: tires are durable, do not readily degrade and are nontoxic

Advantages of Material Types

Rock and Concrete Debris

- low cost material if obtained via construction and demolition activities
- blends in well with the natural environment (rock)
- long term reef material: rock and concrete materials are durable, do not readily degrade and are nontoxic

Vessels

- provides the highest profile with the least labor and/or cost if the vessel is obtained free of charge

Prefabricated Concrete Structures

- has the potential for the greatest habitat complexity
- has the greatest potential to incorporate designs specific to targetted fish and invertebrate species
- long term reef material: concrete structures are durable, do not readily degrade and are nontoxic

Disadvantages of Material Types

Tires

- the second most labour intensive technique for material preparation
- high barge and tugboat transport costs if volunteer placement (e.g. anglers) can not be arranged

Rock and Concrete Debris

- high barge and tugboat transport costs
- heavy machinery costs for placement
- high material costs if materials are not readily available via construction and demolition activities
- care must be taken in placing concrete slabs; slabs tend to plane through the water and settle in areas other than the proposed reef site

Vessels

- high tugboat transport costs
- lowest habitat complexity

Prefabricated Concrete Structures

- high barge and tugboat transport costs
- most labour intensive for material preparation
- heavy machinery costs for placement

Examples of Use

Rock and Concrete Debris

Nanaimo Harbour, Nanaimo, B.C.: In March 1986, 700-1,000 tonnes of scrap concrete was used to construct an artificial reef in Nanaimo Harbour. The scrap concrete material was composed of sewer pipe, "spandeck" hollow cone decking, construction bricks and concrete rubble. The material was transported to the site by barge and placed using a crane shovel to incorporate more habitat complexity and vertical relief than could be attained by simply dumping the material into the water. The reef measures 116 meters in length and averages 15.8 me-

Examples of Use

ters in width. The total reef area is estimated at 1,700 square meters.

Species observed in December 1987 included pile and striped surfperch, rockfish, greenling, lingcod, cabezon, buffalo sculpin, and unidentified flatfish. Fish densities were estimated at 5,800 fish per hectare. Twenty-nine invertebrate species were observed in the study area including plumose anemones, orange trumpet sponges, jingle shells, and tunicates. Three species of algae were observed. The foliose red alga Rhodomenia sp. was present on nearly all exposed reef substrate. Less common algae included Laminaria saccharina and Griffishia sp.

French Creek, Vancouver Island, B.C.: Two small rock rip rap groins were constructed in subtidal waters surrounding the mouth of French Creek in 1983. The rip rap material was placed on sandy substrate. The artificial reef is approximately 88 meters long and averages 23.3 meters wide. The total area of the reef is estimated at 2203 square meters.

Four years after reef construction, diver surveys documented a fish community composed of copper and quillback rockfish, kelp and painted greenling, lingcod, large sculpins, and shiner, striped and pile surfperch. The two species of rockfish accounted for 67% of the total reef fish population. Surfperch accounted for 23.8% of the total reef population. The most abundant macroinvertebrates on the reef were seastars. The second most abundant macroinvertebrate were crabs of the genus Cancer. The most common alga was Gigartina. Other algal species included Laurencia spectabilis, Porphyra perforata, Iridaea sp., Ulva lactuca, and Fucus distichis.

Campbell River, Vancouver Island: In early 1986 an artificial reef was constructed adjacent to Discovery Pier, Campbell River. The objective of the reef is to aggregate fish species for the recreational fishery that occurs off the pier.

The reef is constructed primarily of rock rip rap. The boulders range from 0.5 to 1.5 meters in diameter. The area encompassed by the reef equals 1800 square meters. The reef is located on sandy substrate.

Documented fish species using the reef include red Irish lord, cabezon, copper rockfish, lingcod and kelp greenling. Observed macroinvertebrates include several species of seastars, purple sea urchin and octopus. Macroalgae observed at the site include Cymathere triplicata, Laminaria saccharina, Pleurophycus gardneri, Macrocystis integrifolia, and Iradaea sp.

Concrete Debris, Tires, and Vessels

Porteau Cove, Howe Sound, B.C.: In 1972 eleven "necklaces" of approximately 40-50 tires and four broken tire loops were placed at Porteau Cove. Approximately 500-600 tires were used. Between 1980 and 1985 large concrete blocks weighing 10-40 tonnes each, concrete piles and precast u-shaped sections were end-dumped into the cove. Two wooden ships, the Fort Langley and the Cape Spruce, were sunk in the cove in 1980. A third wooden ship, the Nakaya, was sunk in 1985. In early 1990, damaged sections (H-beams) of the ferry terminal at Horseshoe Bay were transported by barge to the reef site and lower by crane into the cove.

A remarkable diversity of marine life is associated with the concrete debris in the cove. Seventy-six species of conspicuous (i.e. greater than two cm in length or width) invertebrates, twenty species of

Examples of Use

fishes and nineteen species of algae were observed during a monitoring study conducted in late 1989. The most obvious invertebrates were coonstripe shrimps , plumose anemones, sea cucumbers, and gray seastars. Schools of tube-snouts, striped seaperch, pile perch, and shiner perch are abundant. Lingcod, copper rockfish and large numbers of blackeye gobies were observed. Several octopuses are supported by the reef. The structural elements of the concrete debris significantly contribute to the diversity of marine life observed.

The inshore parts of the concrete debris reef appear to support less diversity than offshore sections. This could be due in part to the influence of freshwater runoff from the Squamish and Cheakamus rivers within surface layers of the cove. This decreases salinities in shallower habitats typical of the inshore sections. Many marine animals observed in the deeper offshore sections are known to be intolerant of reduced salinities, and the hostile environment created by freshwater dilution may exclude these animals from shallower habitats.

The tire reef has a low profile and the rubber surface does not provide as stable a substrate as concrete. The interior of the tires, however, serve as excellent crevice space for shrimps, especially coonstripe shrimp and prawn.

The Nakaya is home to thirty-three species of conspicuous invertebrates and 10 species of fish. The surface of the Nakaya is relatively free of attached marine organisms except for a few plumose anemones and expansive growths of spiral tubeworms above the anti-fouling paint. The most abundant invertebrates are the galathied crab and coonstripe shrimp. At certain times of the year massive schools of herring have been observed schooling above the wreck.

The wooden hull of the Nakaya is gradually deteriorating due to the infestation of boring shipworms and parts of the deck have collapsed. The Fort Langley and Cape Spruce have completely deteriorated.

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APPENDIX 1 *Wetland Plants*

Introduction

The following is an identification guide for wetland plant species commonly found in estuarine and marine environments in British Columbia. It supplements the general discussion of wetland ecology presented in Chapter 1. The guide presents only brief descriptions of distinguishing taxonomic features and habitats. Further information may be obtained from reference material cited at the end of this appendix.

Glossary

bract - a specialized leaf from the point of the stem of which a flower or flower stalk arises

bilateral symmetry - structure of a plant, when divided along a single plane, produces two identical structures.

fruit - a mature ovary with its enclosed seed

hummock - a rounded protruding of vegetation lying above the level of adjacent marsh vegetation

inflorescence - the specific arrangement of flowers on flowering plants

inundate - to flood or cover with water

monotypic - referring to one species

panicle- a compound flower head in which the axis is branched one or more times

peduncle - the stem of a solitary flower; the main stem of a flower cluster

petiole - the stem or stalk of a leaf

rhizome - a horizontal underground stem which may bear roots, stems, or leaves

septa - a dividing partition between cavities, referring usually to those spaces within the stem and leaves

sessile - attached directly by the base; lacking a stem or stalk

spike - a type of unbranched inflorescence in which the axis is somewhat elongated and the flowers are numerous and sessile

spikelet - the segment of the inflorescence enclosed by a pair of bracts

subtend – directly below or close to

tuber - an enlarged, fleshy, reproductive structure produced on an underground stem

Plant Species

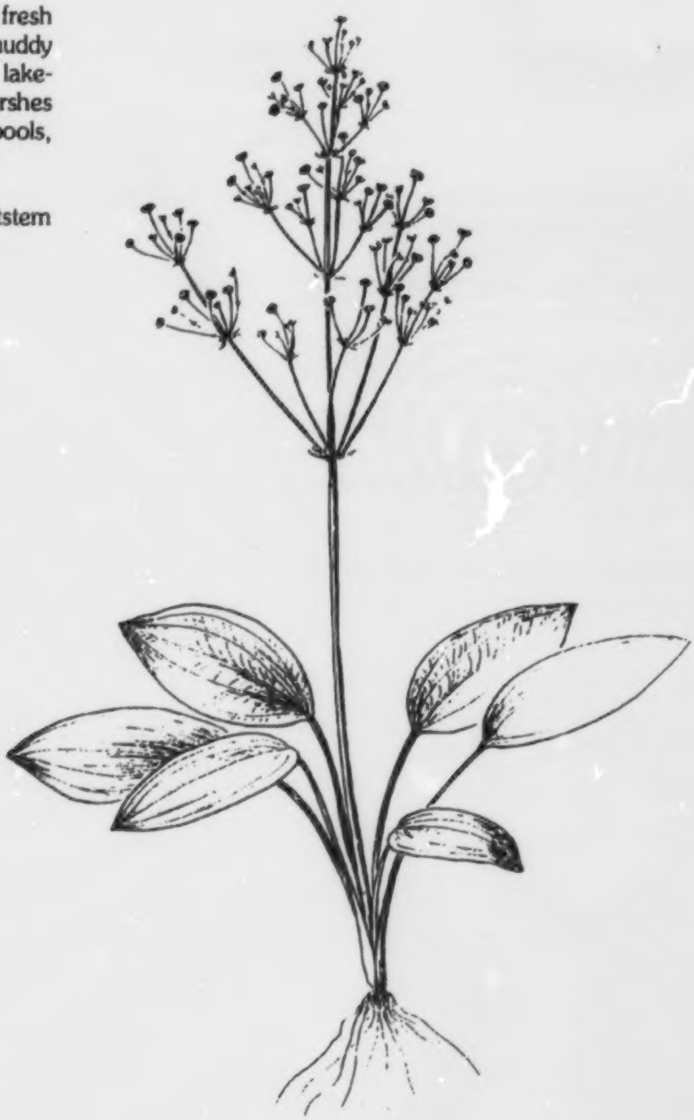
WATER PLANTAIN

Alisma plantago-aquatica

Water plantain is characterized by narrow to oval leaves 3 to 15 cm long. The leaves are found on 10 to 20 cm long petioles that emerge from the base of the plant. The plant's numerous small flowers have 3 distinct petals. They are found on an elaborate panicle and range in colour from white to pink to purple. The plant, including the panicle, may reach 12 dm in height.

Water plantain is common in shallow, protected fresh marshes in water 5 to 15 cm deep. It prefers soft muddy substrate. It may also be found in deep marshes along lakeshores and in wet meadows and swamps. In tidal fresh marshes it may be found high in the intertidal zone, shallow tidal pools, and habitats exhibiting poor drainage.

Common community associates include cattail, softstem and hardstem bulrush, and arrowhead.



Plant Species

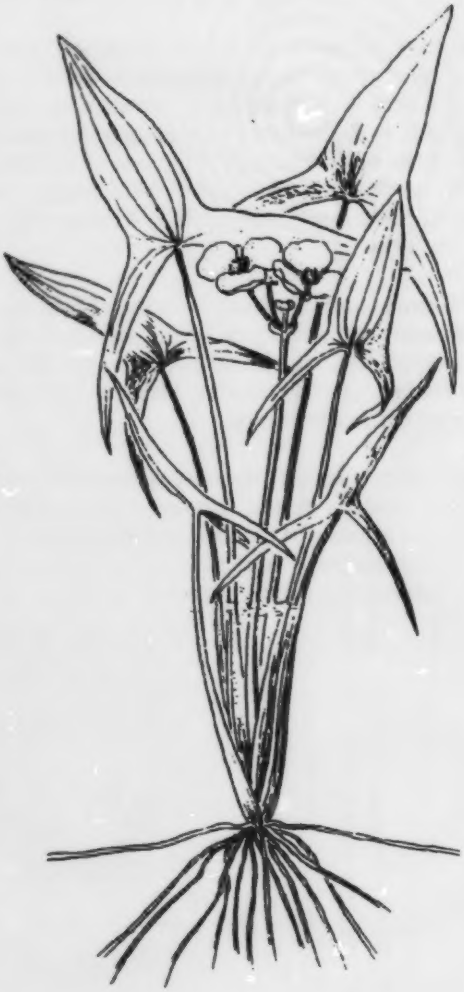
ARROWHEAD

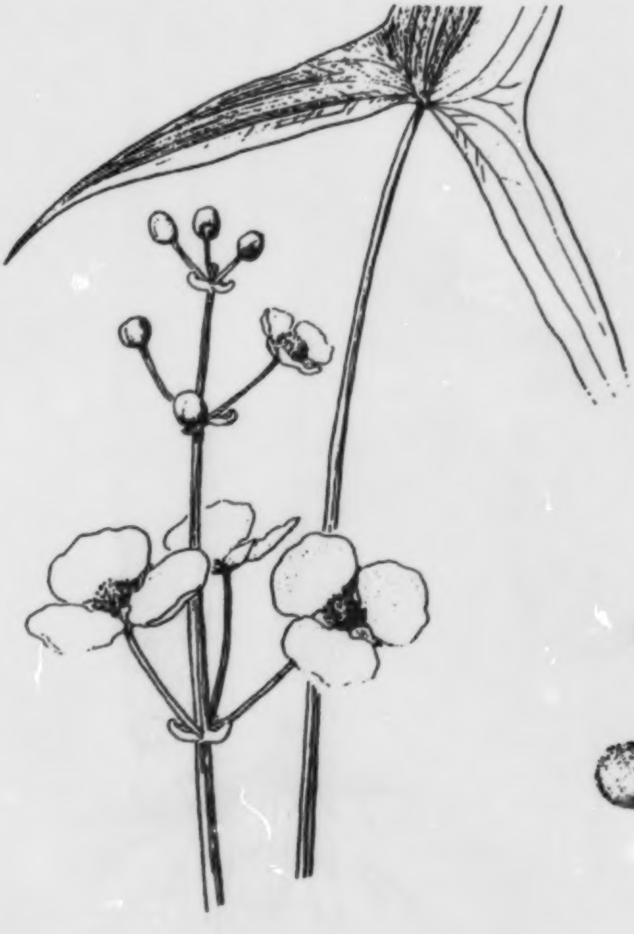
Sagittaria latifolia

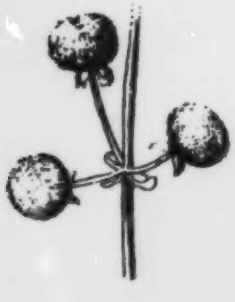
Arrowhead derives its common name from its distinctive arrowhead shaped leaves. The leaves emerge tufted from a tuber-bearing rhizome. Small, approximately 2 cm diameter, singly borne white flowers appear during summer on an elaborate panicle. Each flower possesses 3 petals. Numerous dry fruits develop from each flower. The plant, including the panicle, may reach 50 cm in height.

Arrowhead prefers soft, muddy substrate of protected, shallow fresh marshes. In tidal fresh marshes it may be found high in the intertidal zone, in shallow tidal pools, and habitats exhibiting poor drainage.

Common community associates include cattail, softstem and hardstem bulrush, and water plantain.







Plant Species

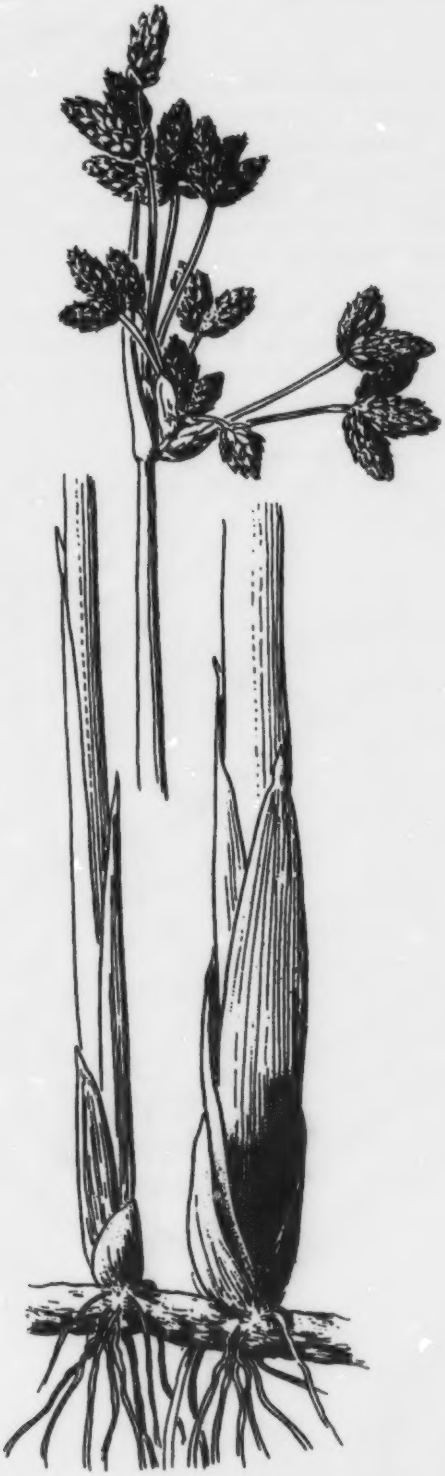
HARDSTEM BULRUSH

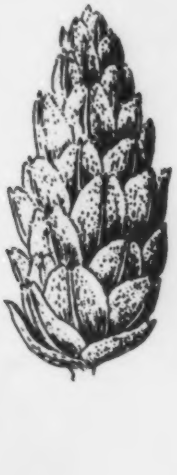
Scirpus acutus

This bulrush grows to 1-3 m in height. The plant is characterized by large woody rhizomes and round stems that measure 1-3 cm thick at the base. The stem cannot be easily crushed between the fingers, hence its common name. The few leaves the plant possesses occur at the base of the stem. A spike bearing about 10 spikelets on short peduncles is located at the top of main stem. A narrow bract 3 to 4 cm in length extends beyond the spike.

Hardstem bulrush occurs in fresh marshes along the margins of lakes in water as deep as 1 m. In fresh and brackish tidal marshes the plant may be found in the low intertidal zone and in areas characterized by standing water or poor drainage. It forms large, monotypic stands.

Common community associates in impounded water habitats of tidal marshes include softstem bulrush, cattail, water plantain, and arrowhead. In tidal marshes, where it occurs in the lower intertidal regions of relatively well-drained habitats, common community associates include spikerush and articulated rush.





Plant Species

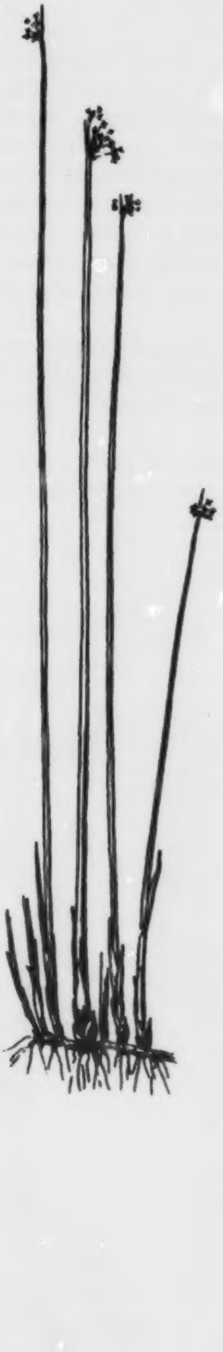
SOFTSTEM BULRUSH

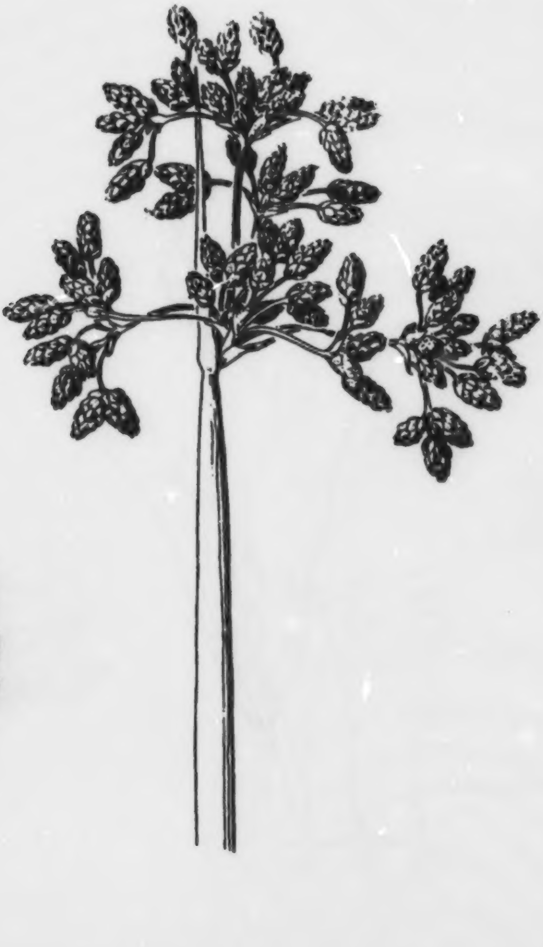
Scirpus validus

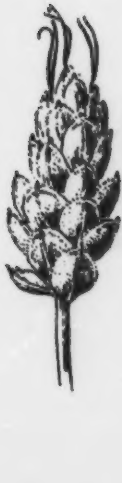
Softstem bulrush is similar in appearance to hardstem bulrush. It is more slender and slightly less taller. The stems are soft and easily crushed between the fingers, hence its common name. The inflorescence tends to be looser and more open. The spikelets are often borne on longer, more droopy peduncles, often singly instead of sessile clusters characteristic of hardstem bulrush. The spikelets are smaller in size on average than hardstem, seldom over 1 cm.

The softstem bulrush occupies the same habitats as hardstem bulrush, but, seldom forms large exclusive colonies typical of hardstem bulrush.

It has the same community associates as hardstem bulrush and is often found with hardstem bulrush.







Plant Species

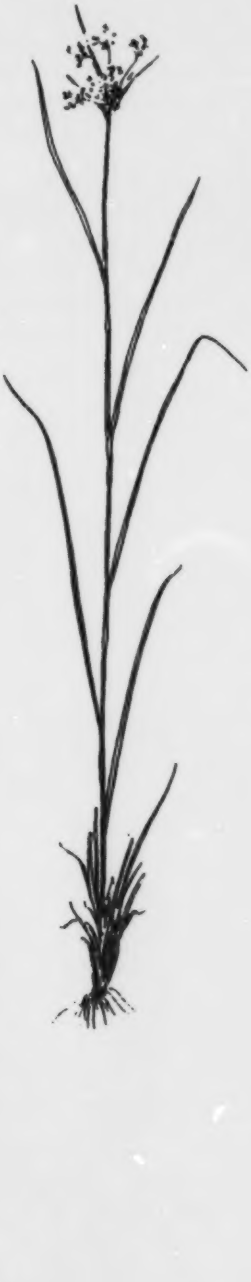
WOOL GRASS

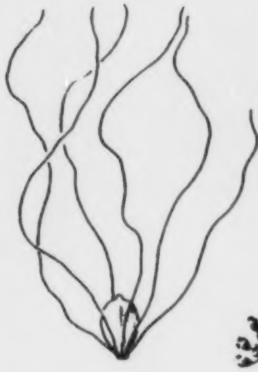
Scirpus cyperinus

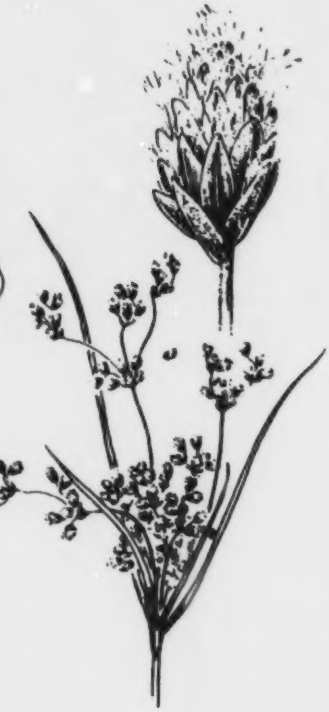
The plant, including the inflorescence, attains heights of 8 to 15 dm. Unlike many other Scirpus species, wool grass does not possess rhizomes. The stems are grouped together forming a distinctive tuft. The leaves are flat and grass-like, and typically 2-6 mm wide. They bear a strong resemblance to *Carex* leaves. The spikes are numerous and small, usually 3-8 mm in length. The spikes are borne on short, slender peduncles in a terminal inflorescence. Scale bristles emerging from the spikes, especially during fruiting, give the spike a woolly appearance.

Wool grass occurs in the mid to high intertidal zones of tidal fresh marshes. It may be found in wet meadows and along the margins of lakes and streams.

Common community associates of wool grass include small-fruited bulrush, soft rush and sedges.







Plant Species

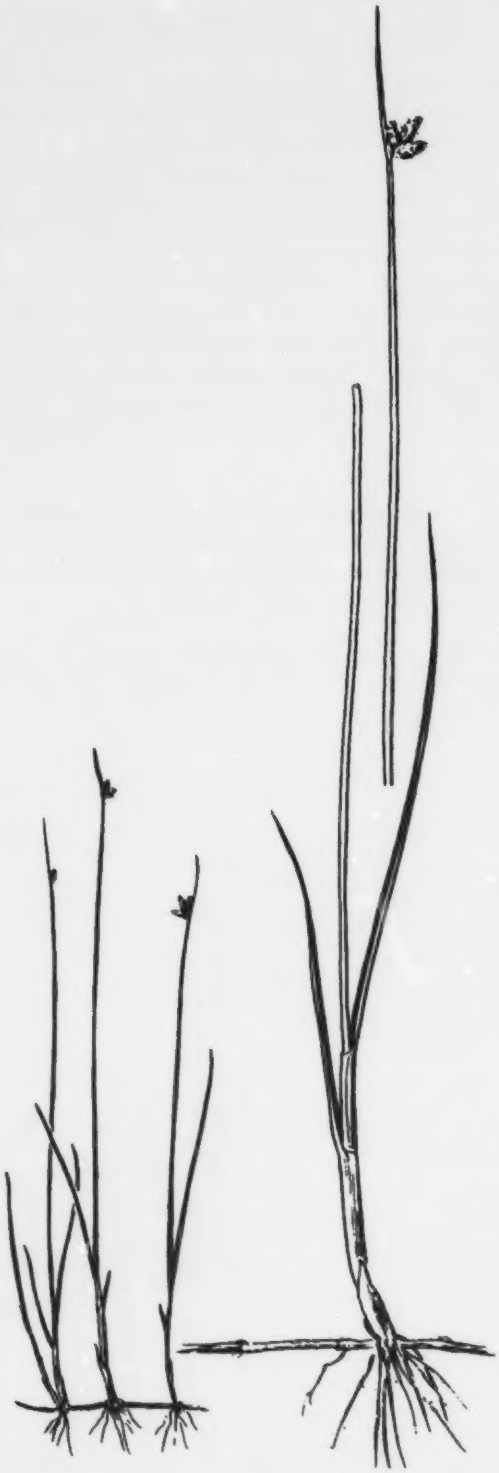
AMERICAN THREESQUARE

Scirpus americanus

American threesquare occurs in loosely organized stands of scattered stems. The stems are triangular with flat to slightly concave or convex sides. Stem height ranges between 1.5 and 15 dm. Several leaves start at or near the stem base. These leaves range from 2 to 4 mm in width to 0.2 to 1.0 m in length. The usual 1-6 spikelets, 7-20 mm long, occur in a sessile compact cluster. The cluster is subtended by a prominent bract that appears to be a continuation of the stem.

American threesquare occurs in low salt and brackish tidal marshes from the mid to high water levels. It may also be found in inland fresh marshes.

Common community associates include seaside arrowgrass and Lyngby's sedge.



Plant Species

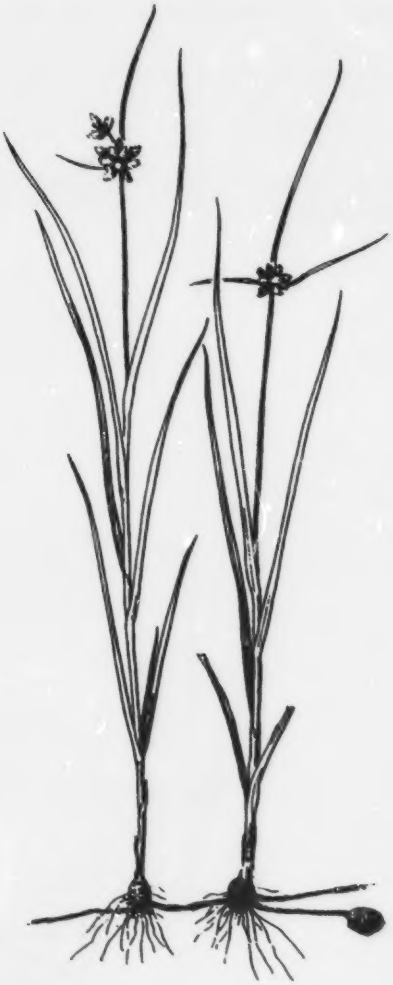
SALTMARSH BULRUSH

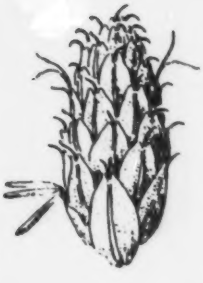
Scirpus maritimus

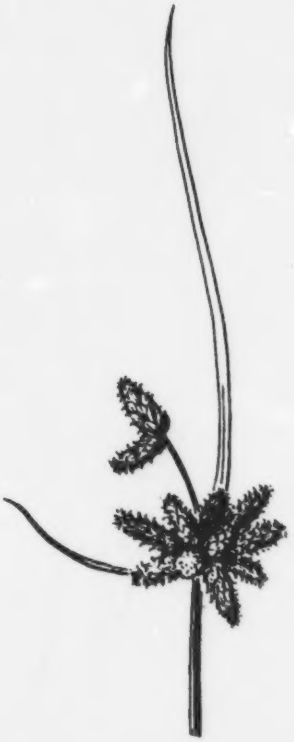
The saltmarsh bulrush attains heights of 2-15 dm. It possesses a sharp triangular stem. Firm tubers are commonly found on the stout rhizomes. The leaves, up to 1 cm wide, are well distributed along the stem. They appear flat or nearly so. Spikelets, 1.2-2 cm long and up to 1 cm wide, number from 3 to 20. Most of the spikelets occur in a sessile, compact, terminal cluster. Subsidiary clusters of spikelets (5-10) sometimes occur on short peduncles (to 5 cm long) emanating from the basal cluster. Several bracts up to 10 cm long extend from the base of the spikelets. This species is often confused with the less common river bulrush, Scirpus fluviatilis. Distinctive features of the river bulrush is the presence of spikelets on the end of 15 cm long peduncles and a thick rhizome without distinctive tubers.

The saltmarsh bulrush most commonly occurs in high brackish or salt tidal marshes that are innundated about once a day. It also occurs less commonly in low salt marshes. The plant may also be found in inland fresh marshes.

Common community associates include American threesquare, hardstem and softstem bulrush, and Lyngby's sedge.







Plant Species

SMALL-FRUITED BULRUSH

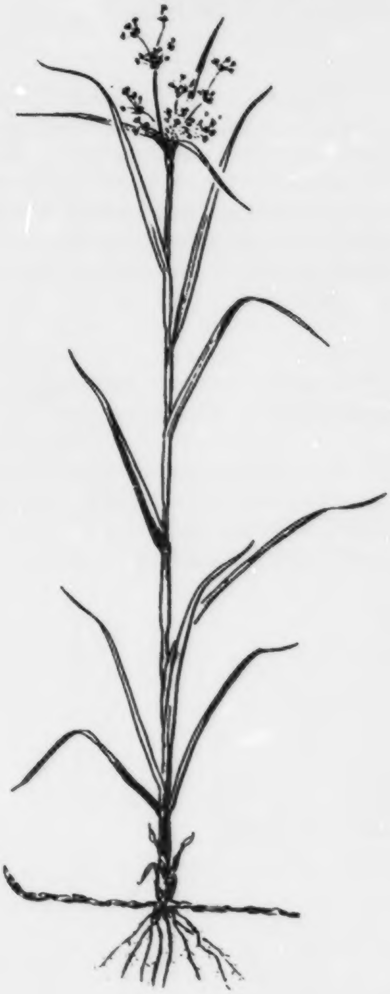
Scirpus microcarpus

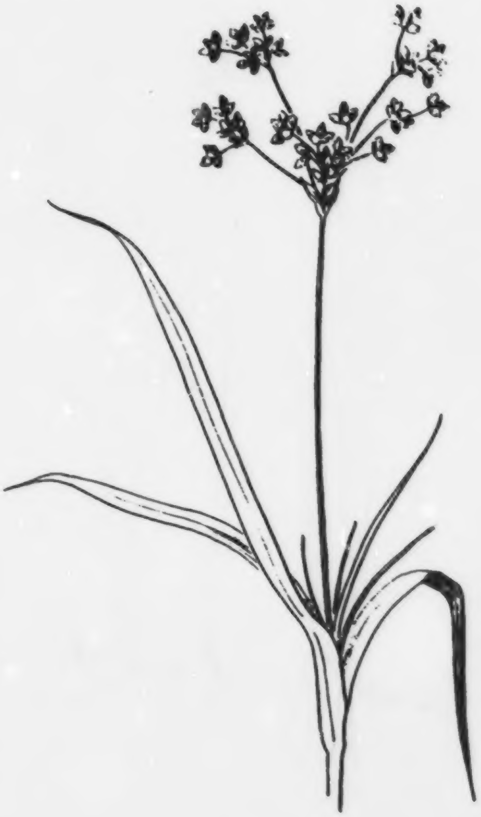
The small-fruited bulrush grows to 6-15 dm in height. The spikelets, 4-6 mm long and ranging from green to black in colour, are borne on several long peduncles that arch loosely from the stem. The distinctly triangular stem is accompanied by several broad 1-2 cm wide leaves. The spikelets are small relative to other closely related members of the genus, hence the common name. The plant possesses well developed creeping rhizomes.

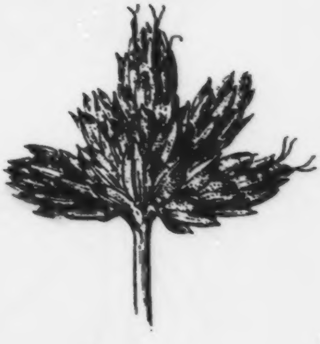
Care must be taken early in the growing season, when the stem and inflorescence are not readily prevalent, not to confuse this bulrush with sedges, especially those sedges that possess wide leaves such as the beaked sedge.

This bulrush inhabits shallow inland fresh marshes, high tidal fresh marshes, and wet meadows. It may be found along the margins of lakes and streams.

Common community associates include wool grass, softstem bulrush and sedges.







Plant Species

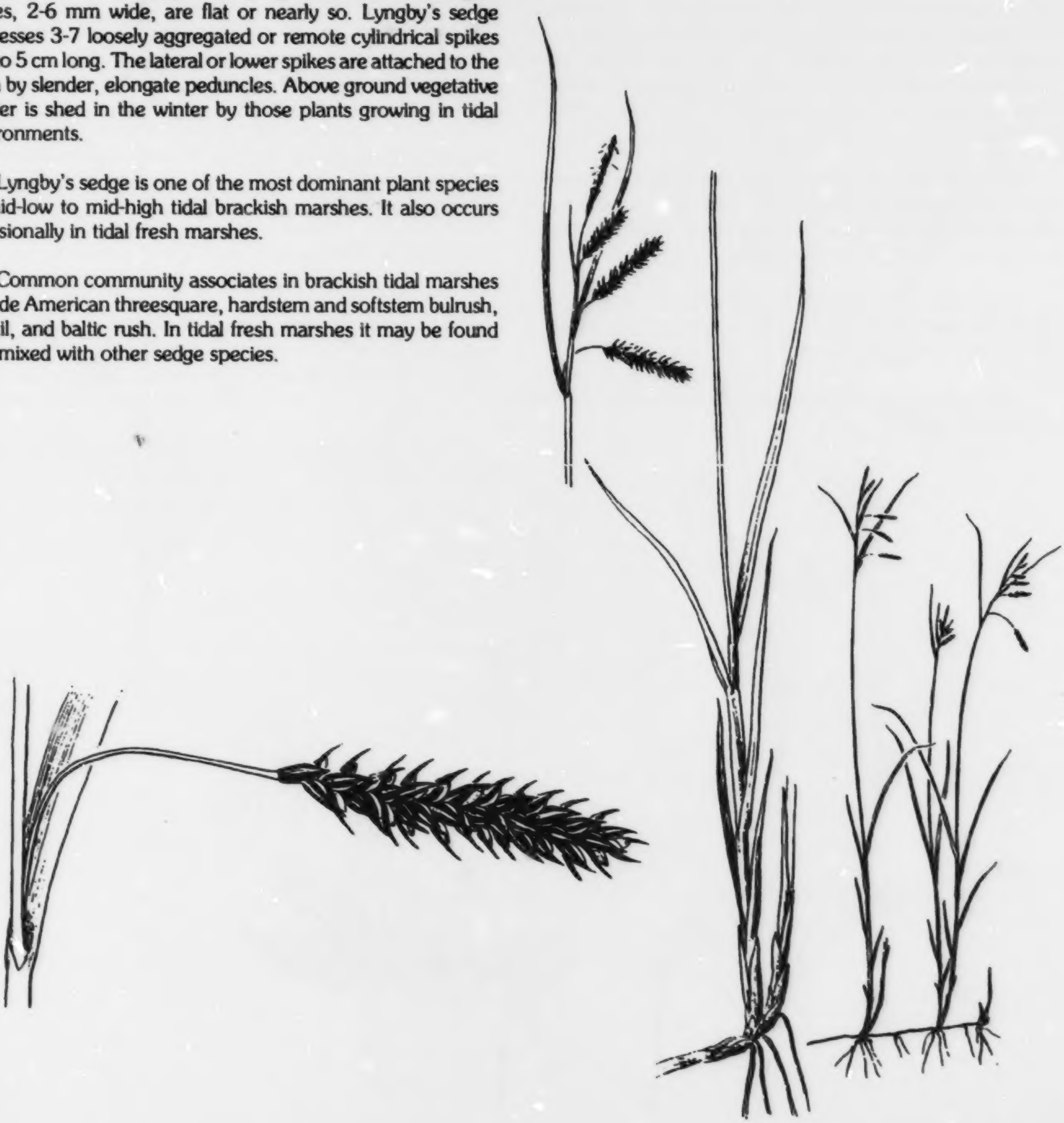
LYNGBY'S SEDGE

Carex lyngbyei

The stems, 1.5 to 10 dm tall, emerge singly or in small clumps from well developed creeping rhizomes. The elongate leaves, 2-6 mm wide, are flat or nearly so. Lyngby's sedge possesses 3-7 loosely aggregated or remote cylindrical spikes 1.5 to 5 cm long. The lateral or lower spikes are attached to the stem by slender, elongate peduncles. Above ground vegetative matter is shed in the winter by those plants growing in tidal environments.

Lyngby's sedge is one of the most dominant plant species of mid-low to mid-high tidal brackish marshes. It also occurs occasionally in tidal fresh marshes.

Common community associates in brackish tidal marshes include American threesquare, hardstem and softstem bulrush, cattail, and baltic rush. In tidal fresh marshes it may be found intermixed with other sedge species.



Plant Species

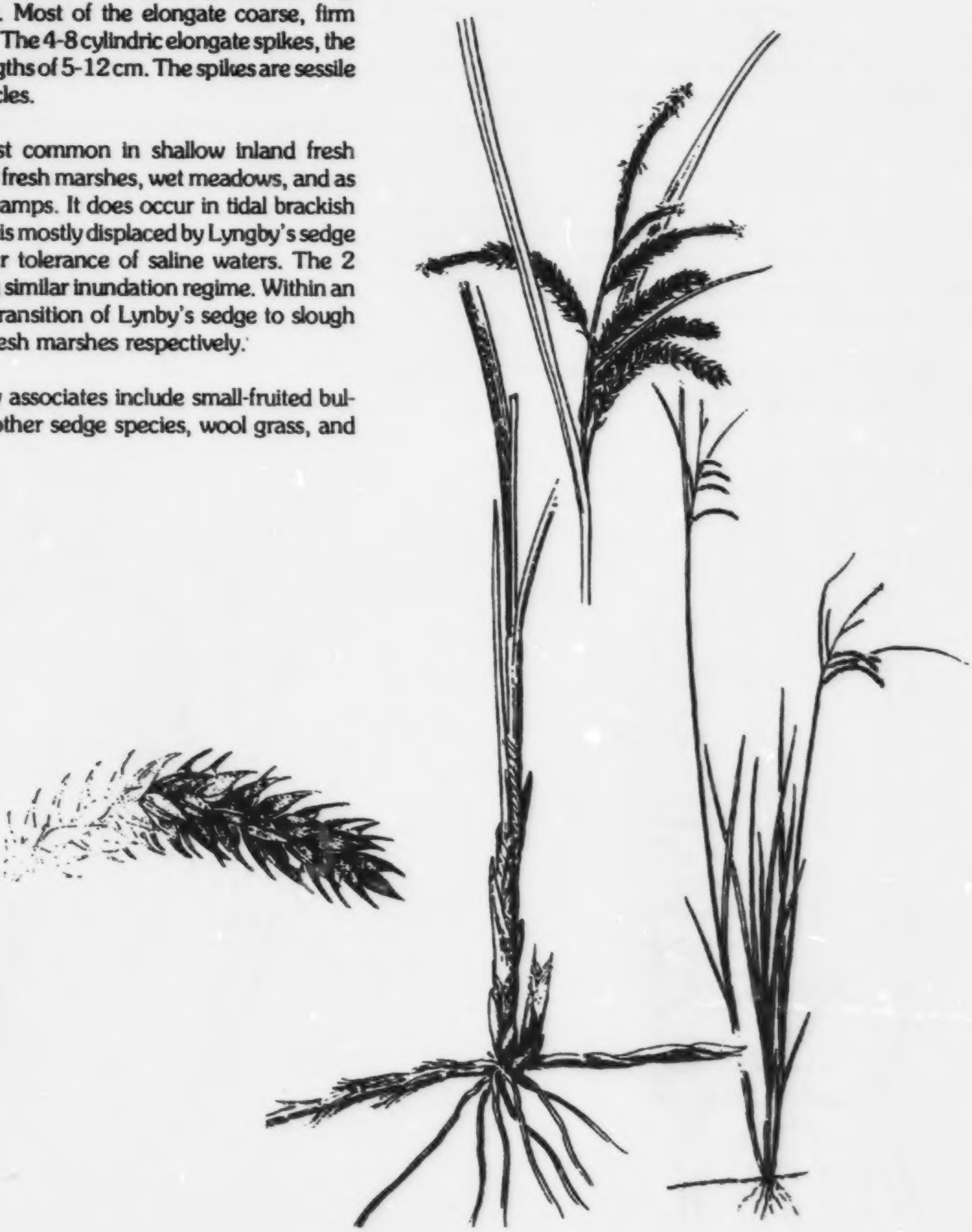
SLOUGH SEDGE

Carex obnupta

The plants are generally characterized by dense tufts of stems attaining heights of 6-15 dm. The plant possesses long, stout, creeping rhizomes. Most of the elongate coarse, firm leaves are 3-10 mm wide. The 4-8 cylindric elongate spikes, the longer nodding, attain lengths of 5-12 cm. The spikes are sessile or borne on short peduncles.

Slough sedge is most common in shallow inland fresh marshes, low to high tidal fresh marshes, wet meadows, and as an understory plant in swamps. It does occur in tidal brackish marshes on occasion, but is mostly displaced by Lyngby's sedge due to the latter's greater tolerance of saline waters. The 2 plants appear to tolerate a similar inundation regime. Within an estuary, there is often a transition of Lynby's sedge to slough sedge from brackish to fresh marshes respectively.

Common community associates include small-fruited bulrush, beaked sedge and other sedge species, wool grass, and reed canary grass.



Plant Species

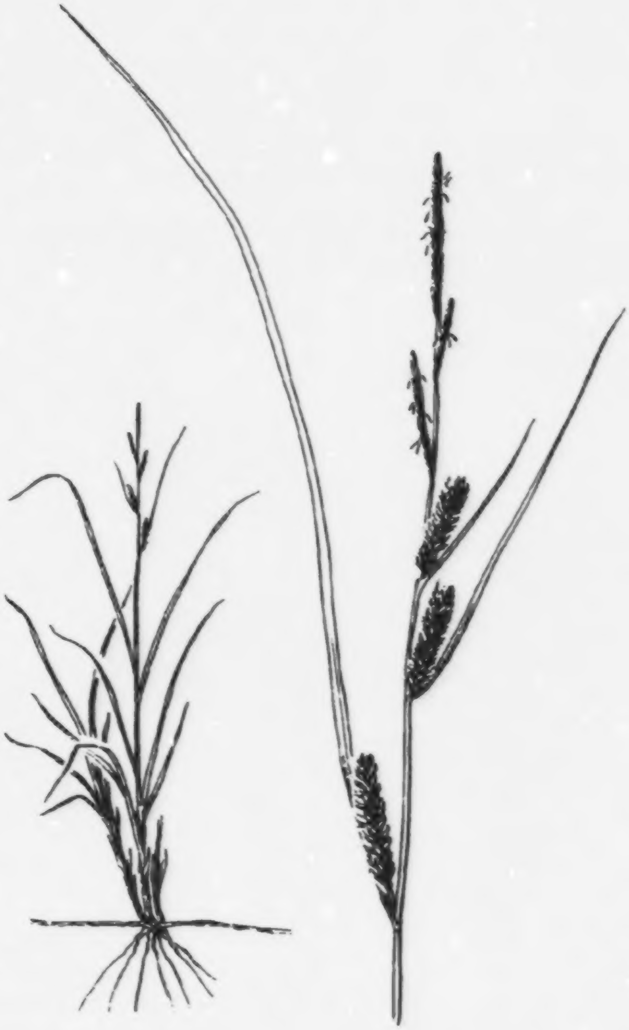
BEAKED SEDGE

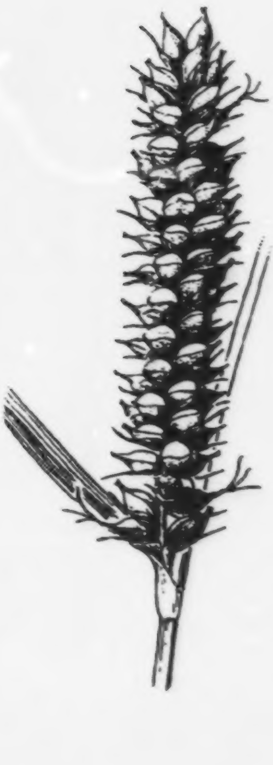
Carex rostrata

The stems, 5 to 12 dm tall, arise singly or few together from stout, elongate creeping rhizomes. The network of rhizomes sometimes form a dense sod. The elongate, relatively thick flat leaves are 4-12 mm wide. The female spikes are 2-7 cm long and about 2-4 cm thick. The male spikes are 2-10 cm long to 1 cm thick. The spikes may be sessile or supported by a short peduncle.

This sedge does not occur in salt or brackish tidal marshes. It is, however, one of the most common sedges in fresh marshes. In non-tidal wetlands it may be found in shallow water at the margin of streams, lakes, or ponds. It also inhabits the more saturated regions of wet meadows. In tidal fresh marshes it may be found in the mid-low to high intertidal zones.

Common community associates include reed canary grass, cattail, and other sedge species.





Plant Species

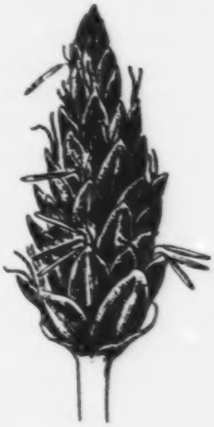
SPIKE RUSH

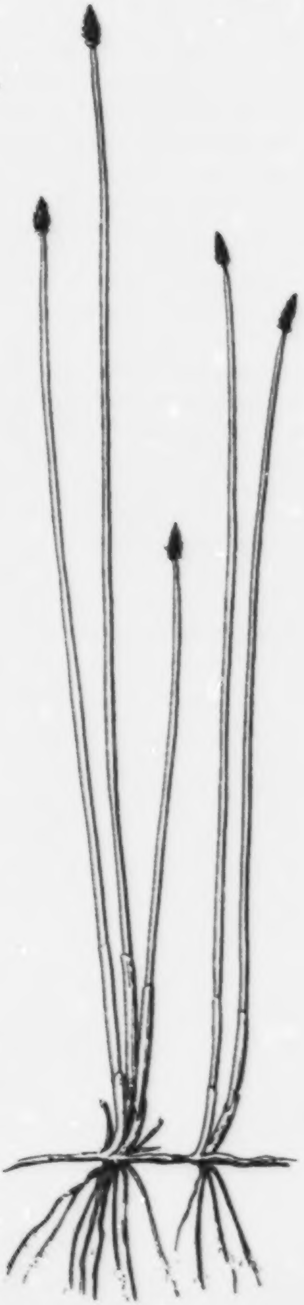
Eleocharis palustris

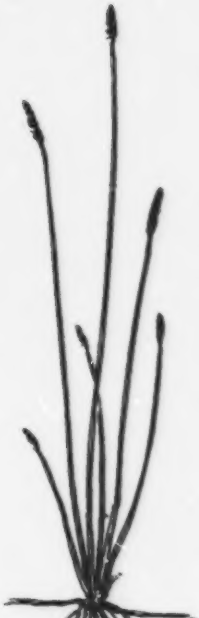
Spikerush attains heights of 1 to 10 dm. The slender to very stout stems are round to oval in cross section. The stems may be scattered or arranged in small clusters on a long creeping rhizome. A solitary terminal spikelet occurs at the end of the stem. The spikelet ranges between 5-23 mm in length.

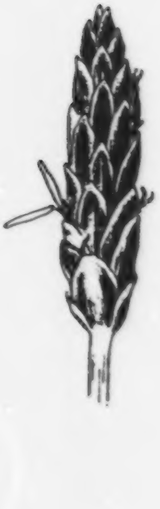
The spikerush may be found forming monotypic stands in the lower intertidal zones of brackish and fresh tidal marshes. It may also be found in shallow inland fresh marshes, wet meadows, and swamps.

Common community associates include both softstem and hardstem bulrush and Lyngby's sedge.









Plant Species

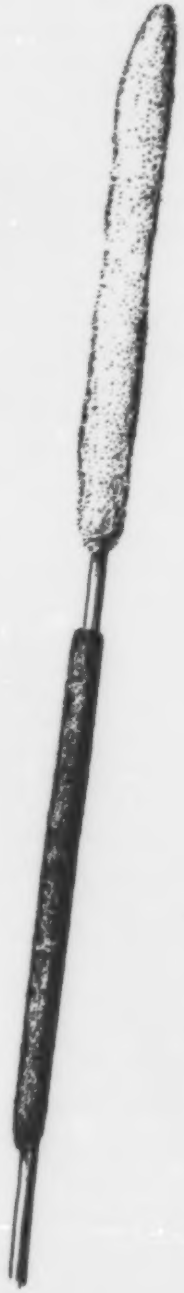
NARROW-LEAVED CATTAIL

Typha angustifolia

The cylindric pithy stems of the narrow-leaved cattail grow to 1- 1.5 m tall. The alternate leaves are sheathing, strap-like, mostly 5 mm broad. They are deep green and convex on the outer surface. The flowers are borne in densely crowded, terminal, cylindrical spike-like inflorescences that are divided into male and female parts. The male part of the inflorescence occurs above the female segment. The male and female segments are separated by 5 to 40 mm. The female inflorescence is the familiar large brown cylinder exhibited upon maturity. It appears distinctly green when immature. It may measure up to 15 mm thick. The male flower appears bright yellow in its actively pollinating phase, becoming a withered spike shortly after flowering.

The narrow-leaved cattail tends to form extensive monotypic stands in both non-tidal and tidal fresh marshes as well as tidal brackish marshes. In shallow fresh non-tidal marshes it tends to grow in shallow water. In tidal habitats it occurs in the high intertidal zone, prospering in areas of poor drainage and water retention. The narrow-leaved cattail is less common than the broad-leaved cattail.

Common community associates include reed canary grass, Lyngby's sedge, beaked sedge, water plantain and arrowhead.



Plant Species

BROAD-LEAVED CATTAIL

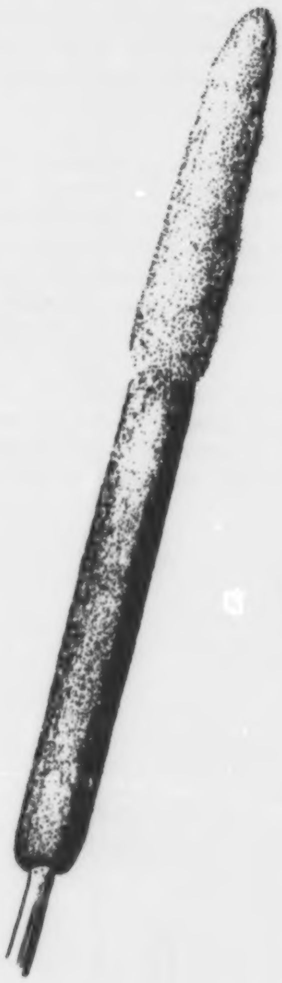
Typha latifolia

The broad-leaved cattail is very similar to the narrow-leaved cattail. The stems range between 1 and 3 meters in height. The leaves are greyish-green, 8-20 mm in width. The female and male segments of the inflorescence are usually continuous. As with the narrow-leaved cattail, the male flowers are situated above the female flowers. The dark brown female cylinder is 12-30 mm thick in fruit.

The broad-leaved cattail and its narrow-leaved counterpart readily hybridize in habitats in which they coexist. This produces progeny that share intermediate characters of the two species.

The broad-leaved cattail is common in a wide range of coastal wetland habitats. It forms vast monotypic stands in non-tidal shallow fresh marshes and high brackish and fresh tidal marshes. It may also be found scattered in road side ditches and wet disturbed areas.

Common community associates of the broad-leaved cattail include reed canary grass, Lyngby's sedge, beaked sedge, water plantain and arrowhead.



Plant Species

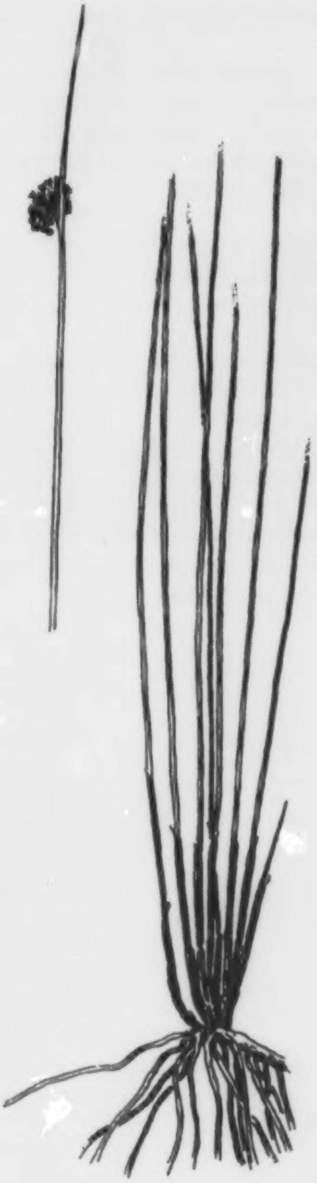
SOFT RUSH

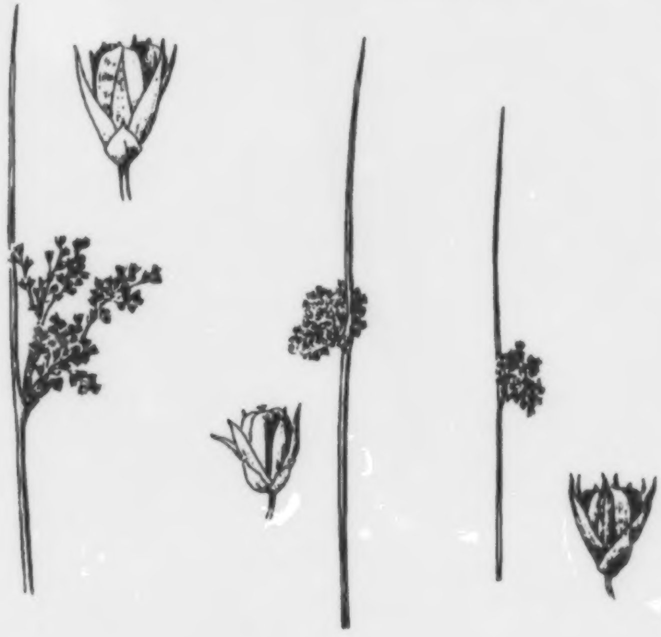
Juncus effusus

This strongly tufted plant possesses cylindrical hollow stems and stout rhizomes. The stems range from 2 to 10 dm in height and 1.5 to 3 mm in thickness. The inflorescence is borne laterally off the stem. The flowers are produced in fairly compact clusters, a few centimetres below the pointed tips of the stems. The soft rush is a highly variable plant, and to the untrained observer specimens from different wetland habitats may appear to be different species. Nine varieties have been identified in North America, four of which are known in the Pacific Northwest.

The soft stem is very common in wet meadows where water may stand in the winter and part of the spring. The plant has been identified as an agricultural pest where crops are sowed in saturated soils. It occurs in shallow fresh marshes where it may form monotypic stands. Though common in tidal fresh marshes, it occurs in isolated patches rarely dominating any particular tidal zone.

In tidal fresh marshes the soft rush is found in communities dominated by sedges and grasses. In shallow inland fresh marshes it may form patches within large stands of cattail. In wet meadows common community associates are grasses.





a) var. pacificus b) var. compactus c) var. gracilis

Plant Species

BALTIC RUSH

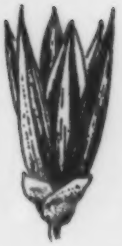
Juncus balticus

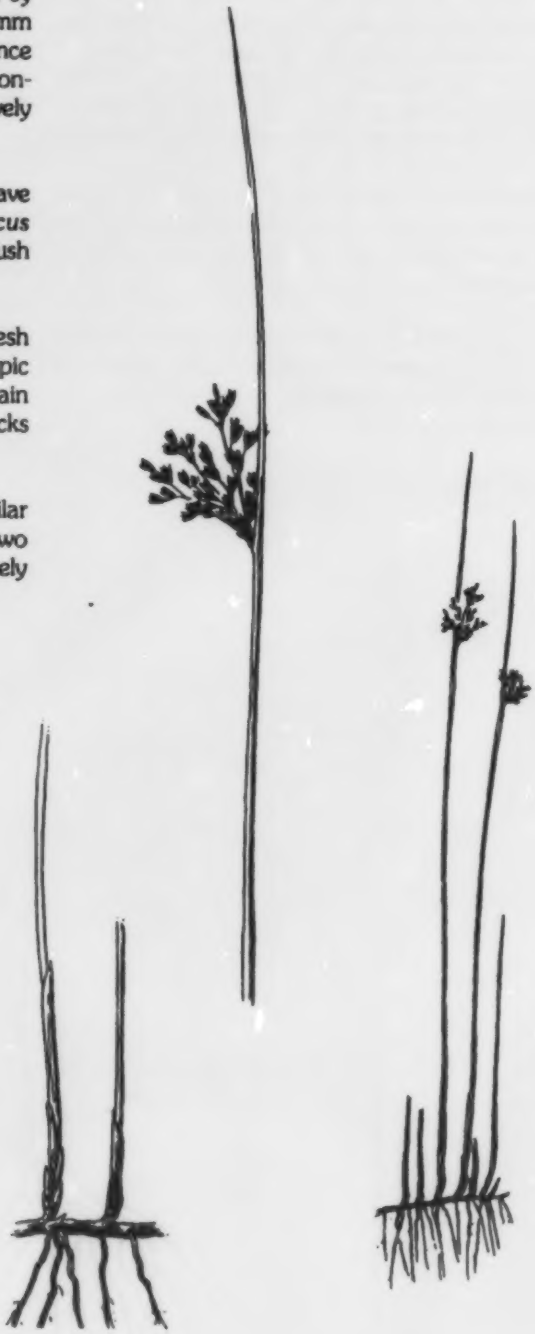
The Baltic rush possesses cylindrical stems supported by thick, wide spreading rhizomes. The stems are 1.5-4.0 mm wide at the base and 1.5 to 8.0 dm tall. A lateral inflorescence branches off from the stem. The inflorescence may be condensed into a discernable head barely 1 cm long or diffusively arranged to 15 cm in length.

The Baltic rush is a highly variable plant. Up to 4 races have been recognized. It is very similar to the Arctic rush, *Juncus arcticus*. Care must also be taken not to confuse the Baltic rush with more slender varieties of soft rush.

This rush may be found in the lower elevations of high fresh and brackish tidal marshes where it often forms large monotypic stands. It appears to prefer tidal habitats that do not retain standing water during low tide. It forms discernable hummocks and may be found inland around alkaline ponds.

The only species under consideration that shares similar environmental requirements is Lyngby's sedge. These two species sometime form a species complex that completely dominates some brackish tidal marshes





Plant Species

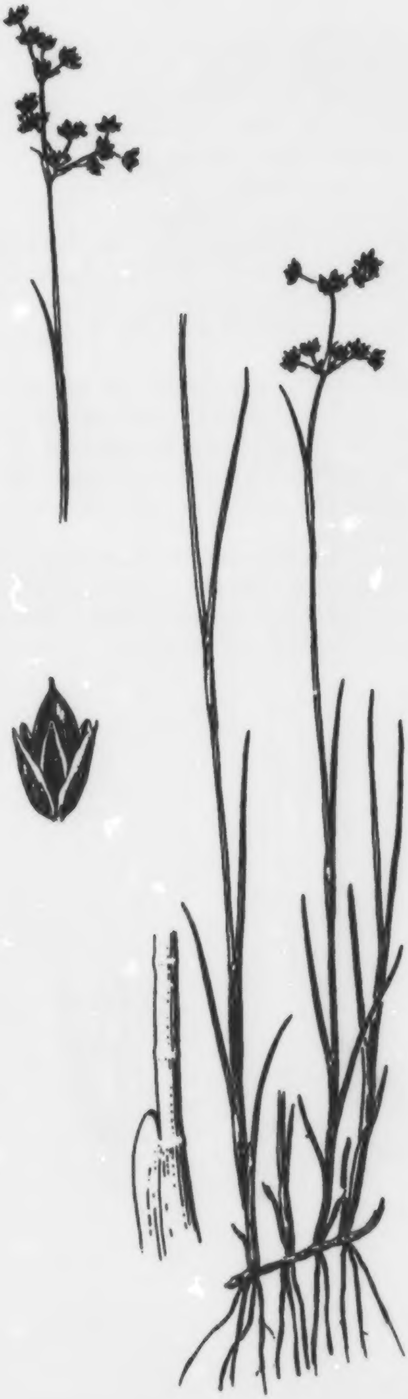
ARTICULATED RUSH

Juncus articulatus

This rush grows to 15-50 cm tall. Larger plants are conspicuously tufted, with secondary plants rooting along the short rhizomes. There are 1-3 leaves per stem. The leaves are round in cross- section and exhibit conspicuous septa. The inflorescence is terminal and consists of numerous small flowering heads of 6-12 flowers, supported on spreading branches.

The articulated rush may be found in low tidal fresh marshes. It may occasionally be found in tidal brackish marshes where freshwater seepage occurs. It may also occur inland in fresh marshes along lake margins and streams.

This plant may be found in the lower range of Lyngby's sedge, and in tidal marshes that retain standing water and support softstem and hardstem bulrush.



Plant Species

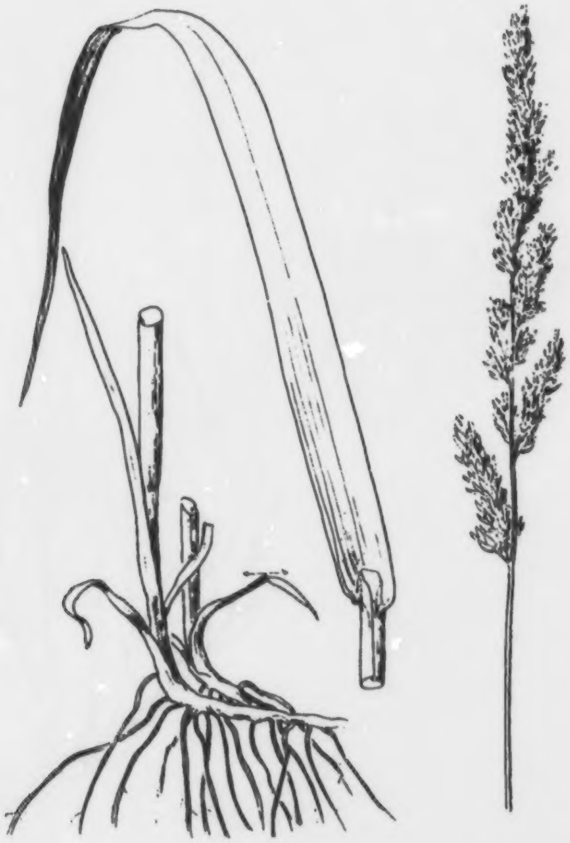
REED CANARY GRASS

Phalaris arundinacea

This strongly rhizomatous grass grows to 7-14 dm tall. The inflorescence ranges between 8-15 cm in length. The inflorescence is borne on the stem high above the leaves. The flat leaves are 7- 20 mm wide and 30 cm long. The stems may be up to 1 cm in diameter.

Reed canary grass is a common wetland species. It occurs where soils are saturated or near saturation during most of the growing season. It does not persist in habitats that are inundated for extended periods of time. It often inhabits the highest elevations of tidal fresh marshes and may be found in wet meadows and other freshwater wetlands that are seasonally inundated.

The most common associates in tidal fresh marshes are broad-leaved and narrow-leaved cattail. In non-tidal fresh marshes it is often associated with a variety of sedge species.



Plant Species

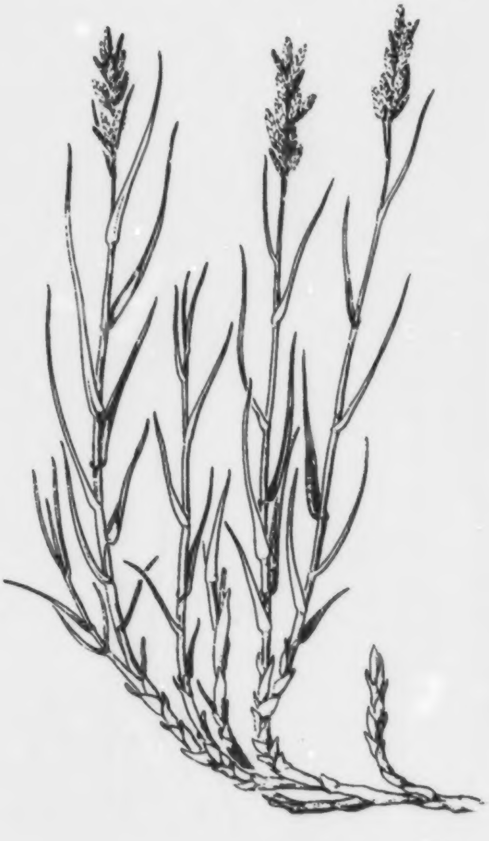
SALTGRASS

Distichlis spicata

This rhizomatous grass usually grows no taller than 30 cm. The robust compressed seed head is 3 to 8 cm in length. The heads are located terminally on solid stems. The bilateral symmetry of the leaves in a single plane is distinctive. The leaves are about 5 cm wide and angle sharply from the stem. The plant actively regulates its salt composition by excreting salt via special cells located in the leaves.

Saltgrass inhabits both the high and low intertidal zones of salt marshes. Through its ability to regulate its salt content it is able to withstand extreme salinities, and may be found in the higher reaches of the salt marsh where active evaporation has created salt pannes. A closely related species, *Distichlis stricta*, inhabits pool margins of alkaline ponds, alkaline flats, and sandy lake shores in non-maritime habitats.

Common community associates of saltgrass include pickleweed and fleshy jaumea.



Plant Species

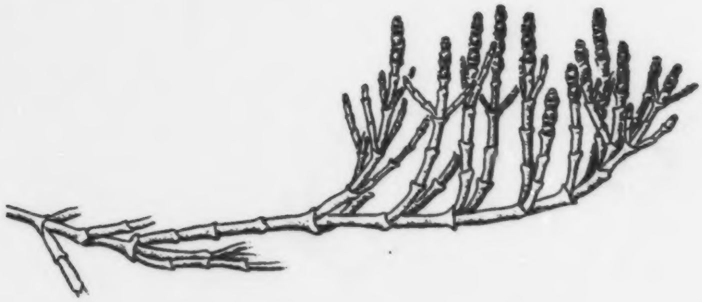
PICKLEWEED, GLASSWORT

Salicornia virginica

This perennial possess no true leaves. Its cylindrical, fleshy stems are distinctive. The freely branching stems may reach up to 1 m in length. Numerous erect flowering stems, mostly 5-30 cm in length, are distinguished by their brownish purple colour and 1-4 cm long flowering spikes. Tiny yellow flowers are clustered at the tips of these stems, emerging from depressions at the joints. This low growing plant forms dense mats up to 20 cm thick. New growth is succulent and may take on a reddish tinge. In winter most of the new growth is lost, leaving only woody perennial stems.

Pickleweed is the most common plant in low salt marshes. It is also common in higher tidal zones of the salt marsh. A less common, annual species of pickleweed may be found in salt marshes. This plant, *Salicornia europaea*, does not possess rhizomes or woody stems.

Common community associates include saltgrass, arrowgrass, and fleshy jaumea.



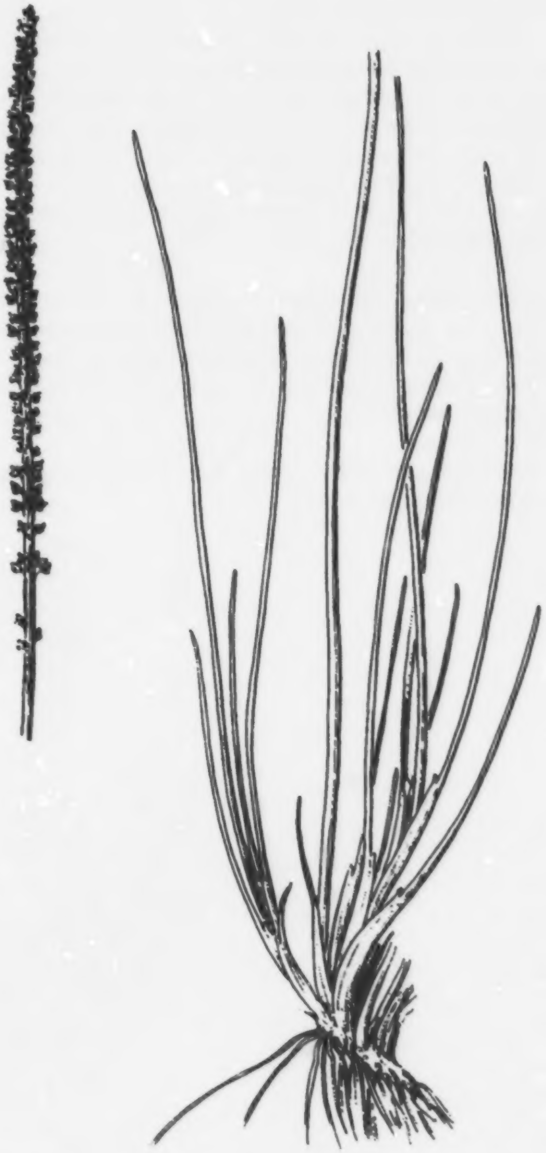
SEASIDE ARROWGRASS

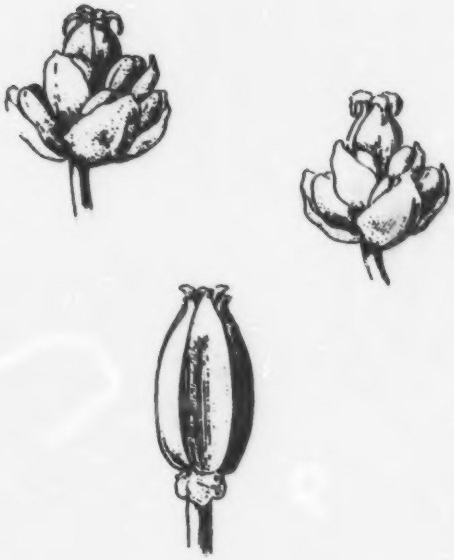
Triglochin maritimum

The flowering stem of arrowgrass extends from the centre of the plant above the leaves. It attains lengths of 3 to 12 dm. Tiny green or purplish flowers are located on numerous individual stalks on the upper third of the stem. The fleshy succulent leaves are 1 to 8 dm in length. The blades are somewhat flattened, 1.5 to 2.5 mm wide. The plants possess heavy, often woody, rhizomes.

Arrowgrass often forms dense stands in low salt and brackish tidal marshes that are inundated twice daily. It may also be found in high marshes that are inundated only once a day, occurring sporadically amongst more dominant vegetation. As with many other brackish and salt marsh plants, arrowgrass sheds its above ground biomass during the winter, maintaining its roots and rhizomes for the next growing season.

Common community associates in brackish marshes include sedges and American threesquare. Common community associates in salt marshes include fleshy jaumea, pickleweed, and saltgrass.





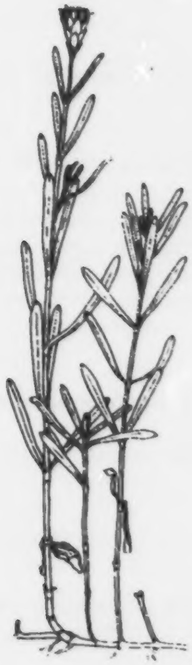
Plant Species

FLESHY JAUMEA

Jaumea carnosa

This succulent rhizomatous perennial grows to 30 cm in height. The stems are lax, giving the plant a matted appearance. The fleshy succulent leaves are 2-6 cm long and 2-6 mm wide. The yellow flower heads are solitary, 1.5 to 2 cm in diameter.

This plant typifies low salt marshes. It forms extensive marshes as a co-dominant with pickleweed. It may form monotypic stands at and above the high water mark.



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APPENDIX 2 *Wetland Plants Used in Marsh Creation*

Plant Species

The following is a summary of harvesting, storage and germination requirements for plant species that have been used in marsh creation projects.

LYNGBY'S SEDGE *Carex lyngbyei*

Seed Harvest, Storage, & Germination: hand gather seed heads from July through September; shatter heads manually to separate seeds; seeds may be stored dry but storage in fresh or brackish water is preferable; germination thermoperiod 10-25° C; storage for at least 180 days has little effect on viability; seed dormancy is a problem

Recommended Propagules: plugs, peat pots, sprigs

Seeding Potential: low

SLOUGH SEDGE *Carex obnupta*

Seed Harvest, Storage, & Germination: hand gather seed heads from July through September; shatter heads manually to separate seeds; seeds may be stored dry or in distilled water, storage in water is recommended to prolong viability; germination thermoperiod 10-25° C; no apparent seed dormancy

Recommended Propagules: plugs, peat pots, sprigs

Seeding Potential: low

SOFTSTEM BULRUSH *Scirpus validus*
HARDSTEM BULRUSH *S. acutus*

Seed Harvest, Storage, & Germination: hand gather seed heads from June through September; shatter heads manually to separate seeds; seeds extremely hard to germinate because they have tough, impermeable seed coats; dry storage ineffective in overcoming dormancy; 180 days storage in brackish and salt water is required to obtain significant seed germination

Recommended Propagules: plugs, peat pots, rhizomes

Seeding Potential: low

AMERICAN THREE-SQUARE *Scirpus americanus*

Seed Harvest, Storage, & Germination: hand gather seed heads from July through October; shatter heads manually to separate seeds; storage in freshwater at 4° C; after ripening occurs

Recommended Propagules: plugs, peat pots, sprigs, seeds

Seeding Potential: high

SALTMARSH BULRUSH *Scirpus maritimus*

Seed Harvest, Storage, & Germination: hand gather seed heads from August through October; shatter heads manually to separate seeds; storage in freshwater at 4° C or dry in closed containers

Recommended Propagules: plugs, peat pots, sprigs, seeds, tubers

Seeding Potential: high

SOFT RUSH *Juncus effusus*

Seed Harvest, Storage, & Germination: hand gather seed heads from June through September; shatter heads manually to separate seeds; store seeds dry or in freshwater at 5° C; germination thermoperiod 10-25° C; seed handling is a problem as the seeds are small and mucilagenous and tend to stick together

Recommended Propagules: plugs, peat pots

Seeding Potential: low

BALTIC RUSH *Juncus balticus*

Seed Harvest: hand gather seed heads from June through August; shatter heads manually to separate seeds

Recommended Propagules: plugs, peat pots

Seeding Potential: low

Plant Species

BROAD LEAVED CATTAIL *Typha latifolia*
NARROW LEAVED CATTAIL *T. angustifolia*

Seed Harvest, Storage, & Germination: hand gather seed heads from September through November; manually break seed head to separate seeds; store seeds dry at room temperature; seed dormancy expressed; 100 percent germination if seed coats ruptured

Recommended Propagules: plugs, rhizomes

Seeding Potential: low

TUFTED HAIRGRASS *Deschampsia caespitosa*

Seed Harvest, Storage, & Germination: hand gather seed heads from July through September; shatter seed heads manually to separate seeds; store dry or in water for 180 day periods; germination thermoperiod 10-25° C

Recommended Propagules: plugs, peat pots, sprigs, seeds

Seeding Potential: high

REED CANARY GRASS *Phalaris arundinacea*

Seed Harvest: Seed commercially available: hand gather seed heads from July through September; shatter heads manually to separate seeds

Recommended Propagules: plugs, peat pots, sprigs, seeds

Seeding Potential: high

SALT GRASS *Distichlis spicata*

Seed Harvest & Storage: seed commercially available; hand gather from August through October; shatter heads manually to separate seeds; dry storage in closed containers at 4° C

Recommended Propagules: plugs, peat pots, sprigs, seeds

Seeding Potential: high

ARROWHEAD *Sagittaria latifolia*

Seed Harvest, Storage, & Germination: hand gather seed heads by cutting stalks from July through September, shatter seed clusters manually to separate seeds; store in freshwater at 4° C; high degree of seed dormancy expressed; poor germination percentage

Recommended Propagules: plugs, peat pots, tubers

Seeding Potential: low

SMARTWEED *Polygonum spp.*

Seed Harvest & Storage: hand gather seed heads from August through October; store dry in closed containers at 5° C or in freshwater at 4° C

Recommended Propagules: plugs, peat pots, seeds, rhizomes, cuttings

Seeding Potential: high

PICKLEWEED *Salicornia virginica*

Seed Harvest & Storage: hand gather seed heads from July through September; seed difficult to obtain; seeds stored dry or in freshwater up to 180 days; little or no seed dormancy; germination thermoperiod 10-25° C

Recommended Propagule: plugs, peat pots, cuttings

Seeding Potential: low

APPENDIX 3 *Riparian Trees and Shrubs*

Introduction

The following is an identification guide to common deciduous riparian trees and shrubs of British Columbia. It is intended to assist in the field identification of local species for use in riparian habitat enhancement projects. The guide presents brief descriptions of distinguishing taxonomic features and habitats. Further information may be obtained from publications presented at the end of the appendix.

Glossary

achene - a small, dry and hard, one-seeded, indehiscent fruit

astringent - sharp or severe, referring to the taste of fruit; to make one's mouth "pucker" upon tasting

bract - a specialized leaf from the point of the stem of which a flower or flower stalk arises

catkin - an erect or lax spike of unisexual flowers without petals

deciduous - describing a plant's habit of shedding leaves at the end of the growing season

distal - the point furthest from the point of origin

dioecious - male and female unisexual flowers are borne on separate plants

flower - a specialized reproductive structure that produces fruits and seeds

fruit - a ripened (fertilized) ovary, together with seed(s) and any other structures that ripen and form a unit with it

gland - a protuberance, appendage, or depression on the surface of a leaf or stem that produces a sticky or greasy viscous substance

glandular - with glands

hemispherical - having the appearance of one half of a sphere

indehiscent - not opening at maturity, not releasing or exposing seed(s)

inflorescence - an organized grouping of flowers on a specialized branch or stem

lenticel - a small porous area on a stem, often slightly raised and of a distinct colour

monoecious - having bisexual flowers or having both male and female unisexual flowers on the same plant

node - a place on a stem where a leaf is, or has been attached

oblong - shaped more or less like a rectangle with round corners

oval - broadly elliptic

ovate - shaped like a long section through a hen's egg with the widest end nearest the base

palmate - like fingers radiating from the palm of a hand; reference to a leaf having three or more lobes arising from a common point

petal - modified leaves, often colourful, surrounding the reproductive structures of a flower

petiole - a leaf stalk

rhizomatous - bearing rhizomes, a rhizome being a creeping underground stem

riparian - inhabiting the banks of a stream or river

stolon - an elongate, creeping stem, on or near the surface of the ground

ultimate node - the last node produced during the previous growing season

Plant Species

RED ALDER

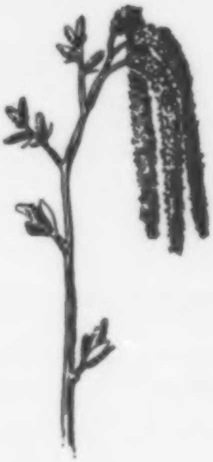
Alnus rubra

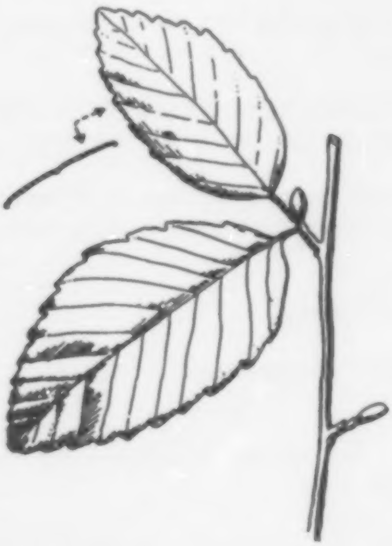
Red alder exhibits different growth forms under varying moisture regimes. In saturated habitats it is shrubby and stunted. In drier environments it may grow to 25 m in height and exhibit a trunk diameter greater than 80 cm.

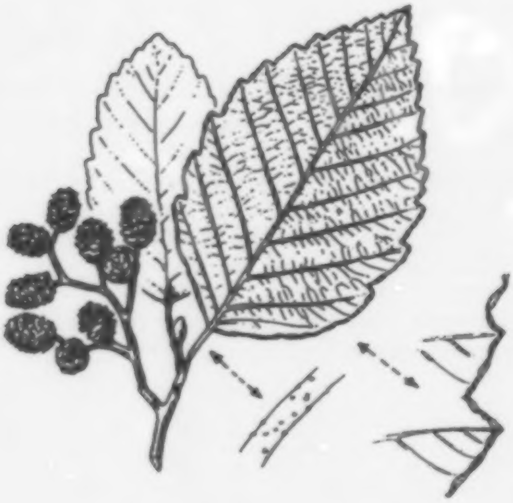
The bark of red alder is usually smooth and dirty gray in colour, often with light patches to give it a mottled appearance. The oval to oblong leaves are usually dark green, heavily veined, and distinctively toothed or notched. They are 5 to 15 cm long and approximately half as wide.

Red alder is monoecious. Male and female flowers are concentrated in separate, erect catkins. The male catkins are cylindrical, approximately 5 mm in diameter and 2 to 5 cm long. The shorter, cone-like female catkins are found on stout peduncles 10 mm long or less. They reach a maximum length and width of about 2.5 cm and 1 cm respectively. Both male and female catkins are produced prior to the emergence of leaves in early spring.

Red alder is very common at lower elevations in British Columbia. It occurs in both wetland and non-wetland environments. The species is common in river bottomlands and floodplains. It may be found in tidally influenced fresh swamps. Red alder is considered intolerant of saline conditions.







Plant Species

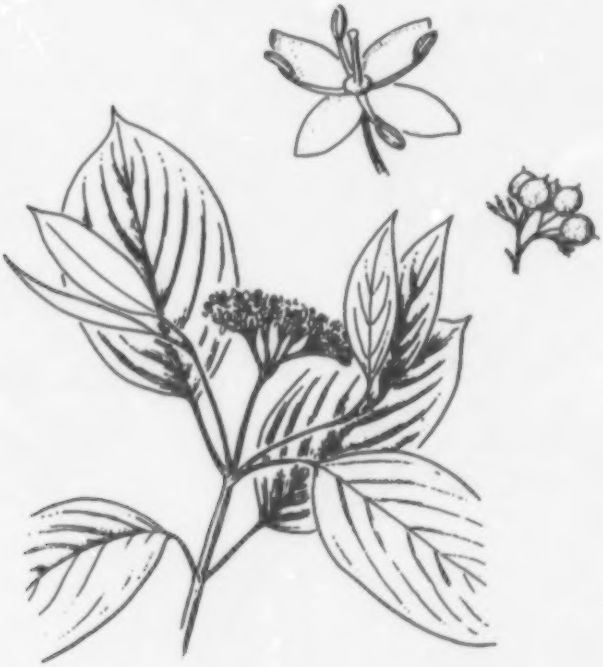
RED-OSIER DOGWOOD

Cornus stolonifera

Red-osier dogwood grows to 6 m in height. It possesses many branches with no readily discernable stem or trunk. The species name describes the plant's habit of producing stolon-like branches (creeping lateral stems that often take root). The younger branches of this shrub are bright red to purplish-red, later turning greyish-green with age. The leaves are 6 to 15 cm in length and approximately half as wide. They are ovate to oval-ovate, with lateral veins that curve prominently toward the pointed leaf tips.

Round white inflorescences, 4 to 7 cm in diameter, appear in spring and summer. The individual 4-petal flowers are 5 mm in diameter. The white to bluish-white berries are 7-9 mm in diameter. The berries are fully ripe in early fall, about the time the leaves of the shrub turn deep red.

This an extremely common shrub of riparian and moist wooded habitats.



Plant Species

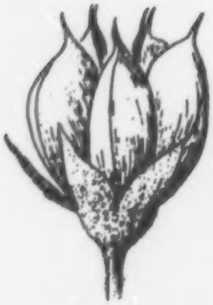
NINEBARK

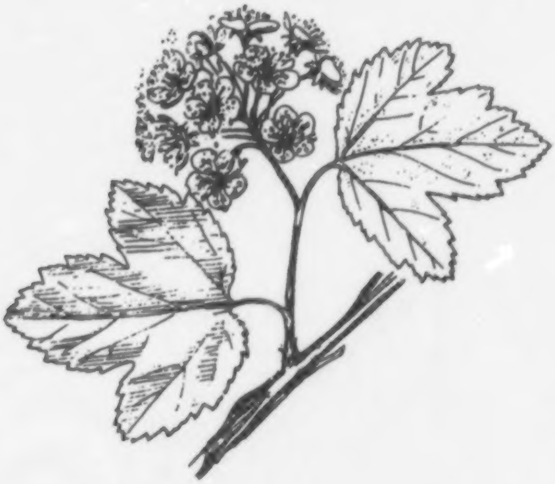
Physocarpus capitatus

This shrub exhibits alternate, palmately lobed leaves about 3 to 6 cm long. It grows to 5 m in height. It has shredded bark on most of its branches. The leaves turn a distinctive yellow in the fall.

The white flowers, possessing 5 petals, form dense, hemispherical inflorescences 5 to 10 cm in diameter. The inflorescences dry and turn light brown in the fall. Small, dry fruits known as achenes are contained within the dry inflorescence.

Ninebark grows along streams and rivers, along the margins of lakes, in swamps and in moist upland habitats. It may be found in fresh tidal wetlands where inundation probably occurs no more than once a day, but where saturation is almost continuous.





Plant Species

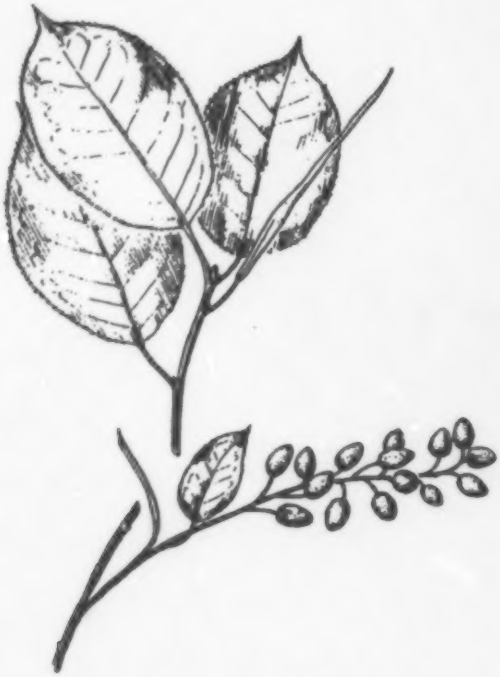
WESTERN CRABAPPLE

Pyrus fusca

Crabapple attains heights of 3 to 12 m. The leaves are narrowly ovate to oval, with an occasional lobe on one or both margins of the leaf.

Crabapple blossoms in April and May. The 2 to 3 cm diameter flowers are white to pink-purple and possess five petals. The flowers occur in clusters. The fruits are smaller than cherries, less than 2 cm in diameter, and yellowish to purplish-red when ripe.

This is a relatively common shrub in coastal lowlands to 1,500 m. The species may be found along streams and rivers, swamps, bogs, and wet meadows.



Plant Species

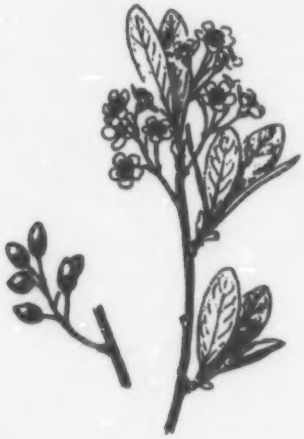
BITTER CHERRY

Prunus emarginata

Bitter cherry ranges in habit from straggly shrubs 2 m tall to tall, erect trees 15 m in height. The bark of young trees is a deep reddish-purple. The bark colour changes to a greyish-brown as the trees age. The bark is marked with greyish lenticels up 5 cm long. The highly variable leaves, oval to oblong to narrowly ovate, all possess glands near the junction with the petiole. The leaves are finely toothed and range between 3 and 8 cm in length.

Bitter cherry blossoms in April and May. The flowers possess 5 white petals. The flowers are grouped in round clusters near the ends of the limbs. These develop into 8 to 12 mm long red to almost black berries. The berries are very bitter.

In drier regions of the province bitter cherry is found adjacent to streams and rivers. In wetter regions, such as those along the coast, it found in deciduous and mixed forest communities.



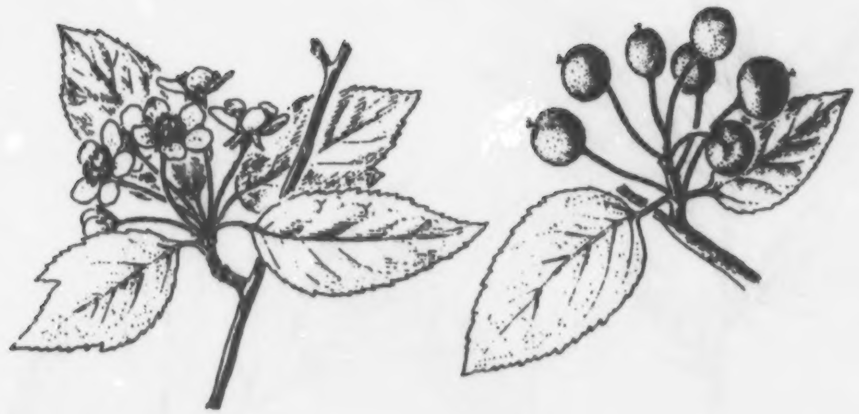
Plant Species

CHOKE CHERRY

Prunus virginiana

This cherry grows as an erect shrub to a small tree 1 to 4 m in height. The bark is purplish-gray and is roughened by numerous small fissures. The leaves are 4 to 10 cm long. The leaf margins are finely toothed and are oval to narrowly ovate-oblong in shape. The petioles bear 1 to 2 distal glands.

The blossoms are most prevalent in May. The white flowers are concentrated within a dense, cylindrical inflorescence near the ends of the limbs. These develop into red, purple to black berries 8 to 11 mm long. The berries are sweet but astringent.



Plant Species

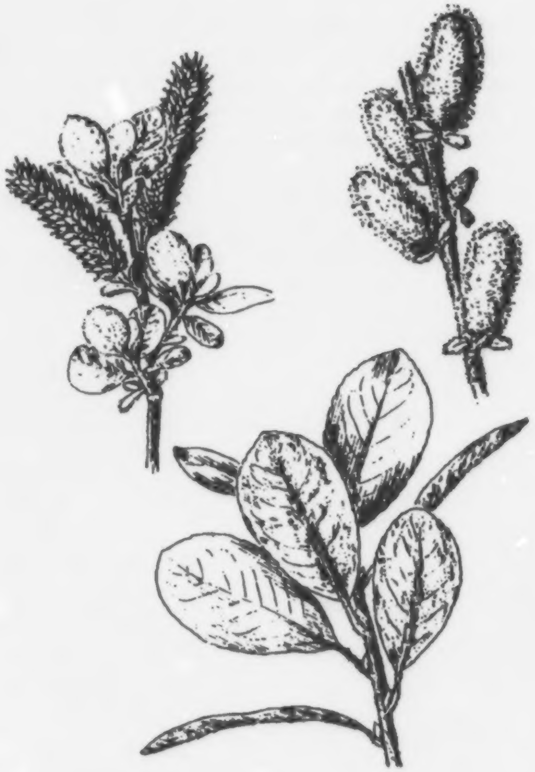
WILLOW

Salix spp.

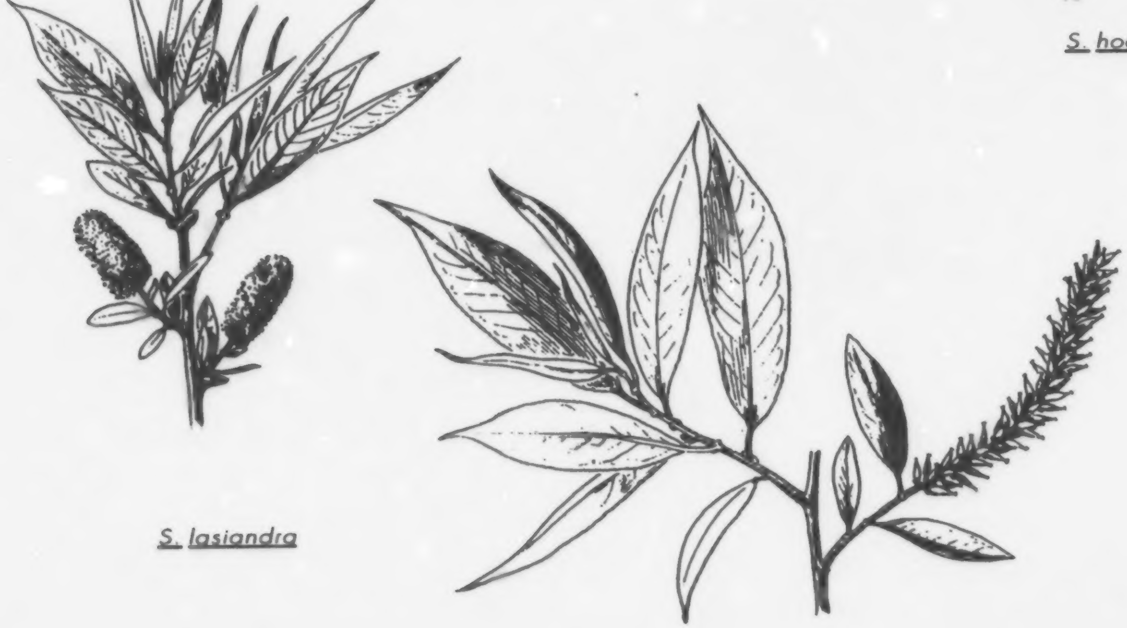
Forty-two species of willow occur in British Columbia. Of these, thirty-eight are native and four are introduced. Willows are dioicous. The unisexual flowers are congregated within an erect or lax catkin. The catkin is the main feature between differentiating *Salix* species. Unfortunately, the catkins are only prevalent during late winter and early spring. In the absence of catkins, mature leaves and twigs are used to identify species.

The leaves of willows are generally elongated. They vary from round to extremely narrow. The length varies from 2 to 10 cm. Willows are generally tall shrubs or short trees (4 to 8 m) but can reach 20 m in height.

Willows are common along streams, rivers, and fresh and brackish tidal wetlands. Some of the more common species found in these wet environments include the sandbar willows (*S. exigua, S. sessifolia, S. argophylla, S. caudata*), Pacific willow (*S. lasiandra*), Sitka willow (*S. sitchensis*), Scouler's willow (*S. hookeriana*) and Mackenzie or yellow willow (*S. rigida*). During the growing season willows can withstand temporary inundation, but not prolonged flooding. Willows are generally tolerant of a wide range of environmental conditions.



S. hookeriana



S. lasiandra

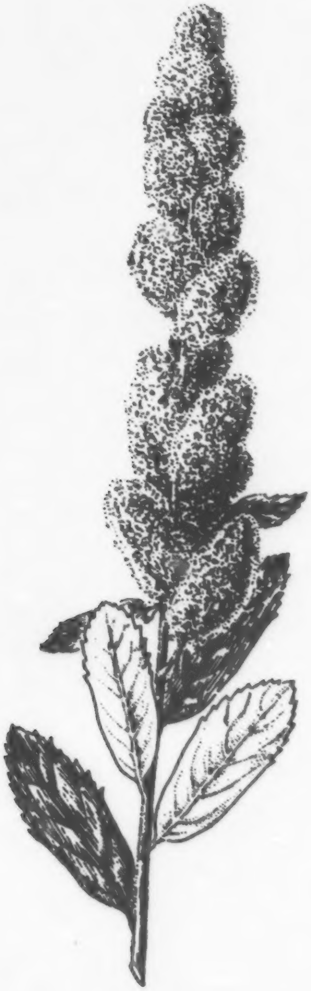
Plant Species

HARDHACK

Spiraea douglasii

Hardhack reaches heights of 1.5 to 2.5 m. It possesses terminally notched leaves 3 to 8 cm long. When in summer bloom, the shrub is readily identifiable by 1 to 2 dm long pink, terminal inflorescences. The flowers turn brown soon after flowering and may persist throughout the winter.

Hardhack is most common in swamps and bogs. It is also common in tidal fresh swamps. It appears to be a transitional species that dominates the vegetative community of old marshes that are slowly evolving into terrestrial communities. Hardhack frequently occurs in wet meadows and roadside ditches as well as along streams. It rarely dominates riparian communities.



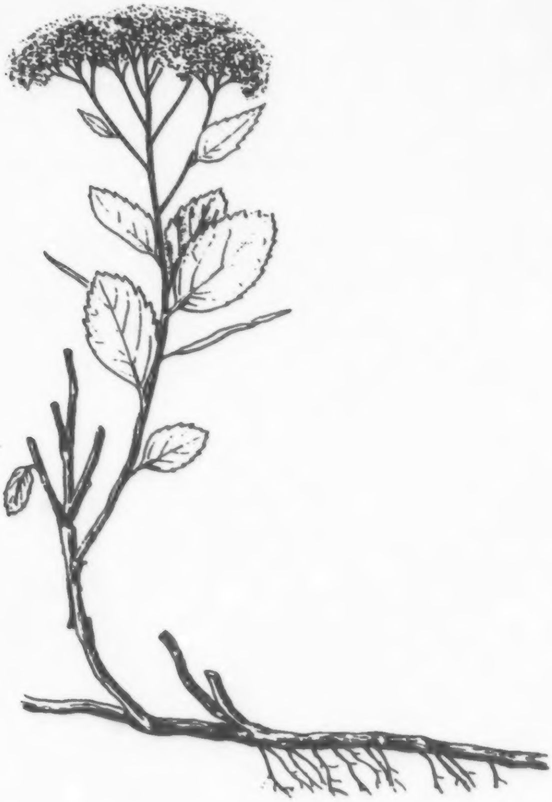
Plant Species

FLAT-TOP SPIREA

Spiraea betulifolia

This small shrub reaches heights of 2.5 to 6 dm. The oval to oblong leaves are 2 to 7 cm long and marginally toothed from the middle of the leaf to the tip. Flat-top spirea flowers during June and July. The white to faintly pinkish or lavender flowers are concentrated in a nearly flat-topped inflorescence.

Flat-top spirea is found in moist habitats such as those adjacent to streams and rivers and the margins of lakes and marshes. It also inhabits relatively dry areas such as rocky, well-drained hillsides.



Plant Species

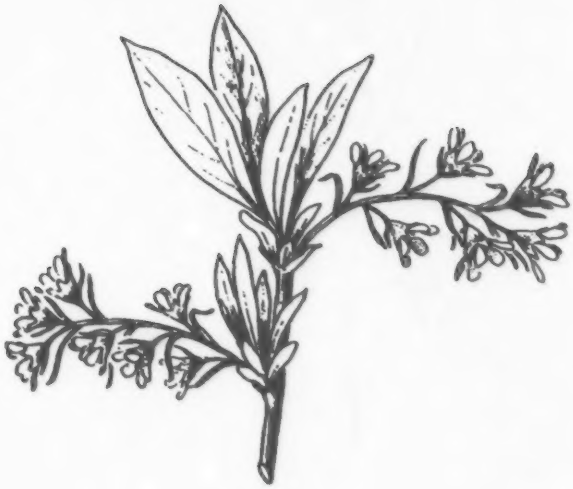
INDIAN PLUM/OSOBERRY

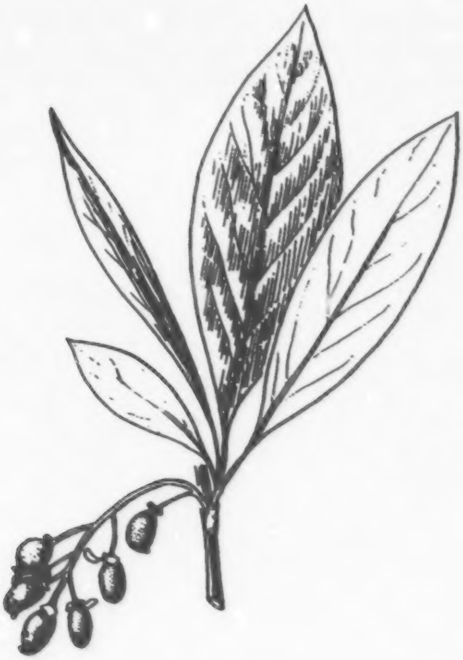
Osmaronia cerasiformis

Indian plum grows to a height of approximately 4 m. The leaves, narrowly ovate to oval, may reach 10 cm in length.

Indian plum is dioecious. It blossoms in February and early March, before the first leaves emerge. The flowers are borne in elongated clusters approximately 1 cm in diameter. The 5 petals are greenish white. The bright orange fruits ripen between June and August.

Indian plum is found along streams and rivers in fairly open environments. It also occurs in dry wooded habitats.





Plant Species

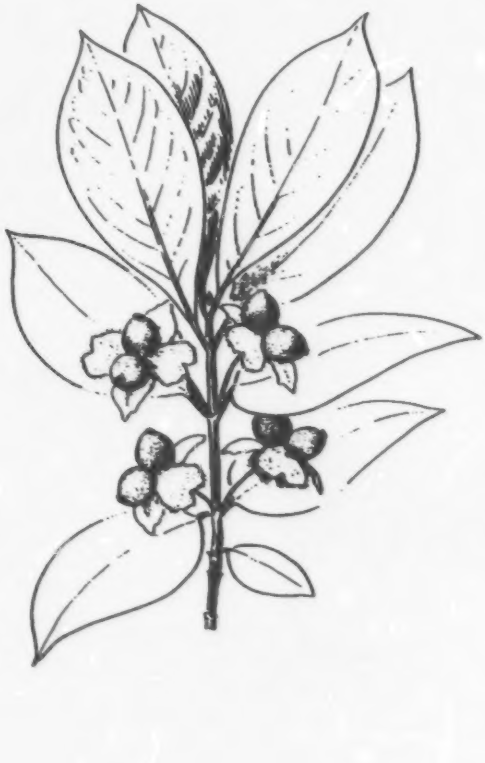
HONEYSUCKLE/TWIN BERRY

Lonicera involucrata

Honeysuckle grows to 4 m in height. Young stems of the plant are quadrangular. The dark green, almost leathery, narrow oval leaves are 5 to 14 cm long and 2 to 8 cm wide. They are borne on very short petioles.

This tall shrub blossoms during May and June. The narrow flowers are typically borne in pairs. They possess yellow petals that are joined for most of their length. Beneath each flower are two pairs of leafy bracts. The bracts become purplish red as the berries develop. The berries ripen during July and August. They are black and about 1 cm in diameter.

Twin berry grows in dense thickets in shrub swamps. It is common along the perimeter of coastal lakes and is found along streams and rivers where a dense canopy of trees is absent.



Plant Species

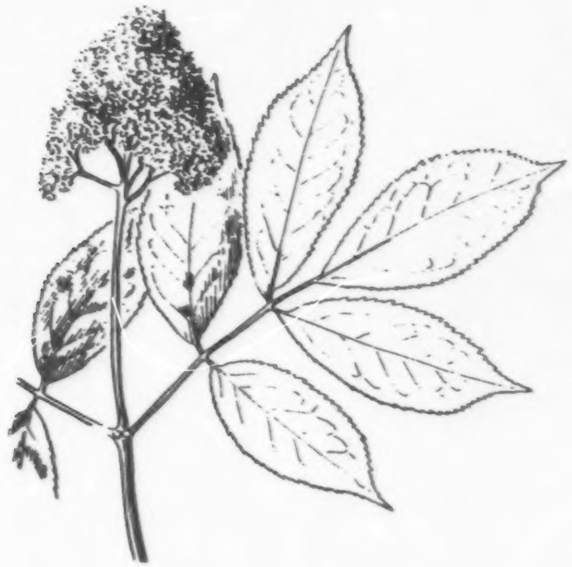
RED ELDERBERRY

Sambucus racemosa

The red elderberry attains heights of 4 to 6 m. Its leaves generally have five to seven leaflets. The leaflets are strongly serrated, narrowly ovate to oval, 4.5 to 17 cm long and 2 to 6 cm wide.

The small, cream coloured flowers are organized into a dense, pyramidal inflorescence. Flowering commences in May and continues through the early part of June. The berries ripen during June through July. The berries are 5 mm in diameter and are usually bright red, however, some plants do produce yellow or white berries.

Red elderberry thrives in open, wet habitats. It is common along streams and the edges of damp, coniferous forests. It is a common plant of shrub swamps.



Plant Species

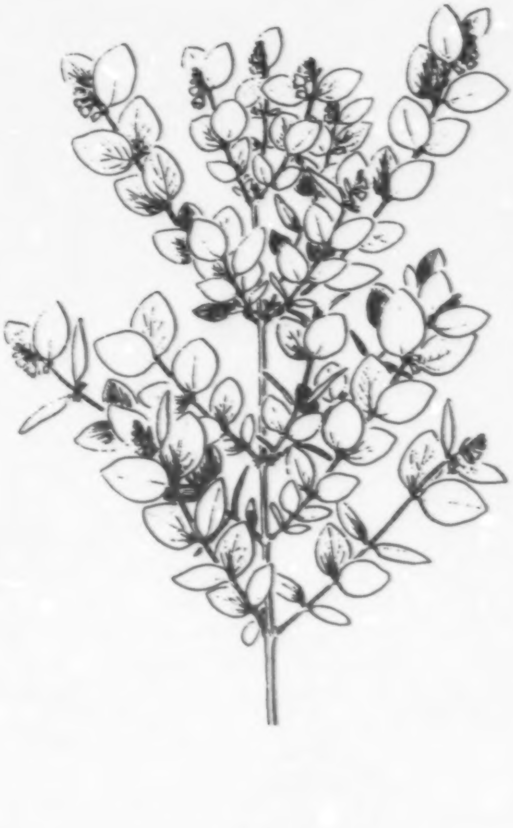
SNOWBERRY

Symphoricarpos albus

Snowberry grows to a height of 2 m. The leaves are borne in pairs. The size and shape of the leaves are highly variable. On old growth the leaves are generally oval, 1.5 to 5 cm long and 1 to 3.5 cm wide. Stems of relatively recent growth often produce larger leaves that are irregularly lobed.

The flowers display 5 pink petals that are united for much of their length. They are rarely longer than 7 mm. The flowers bloom from spring to early fall. The white fruits are more or less round to oval in shape, the larger ones 1 to 1.5 cm in length.

This shrub is found in a wide range of habitats. It occurs in densely wooded habitats as well as exposed slopes. It is a very common component of riparian shrub communities in southwestern British Columbia.



Plant Species

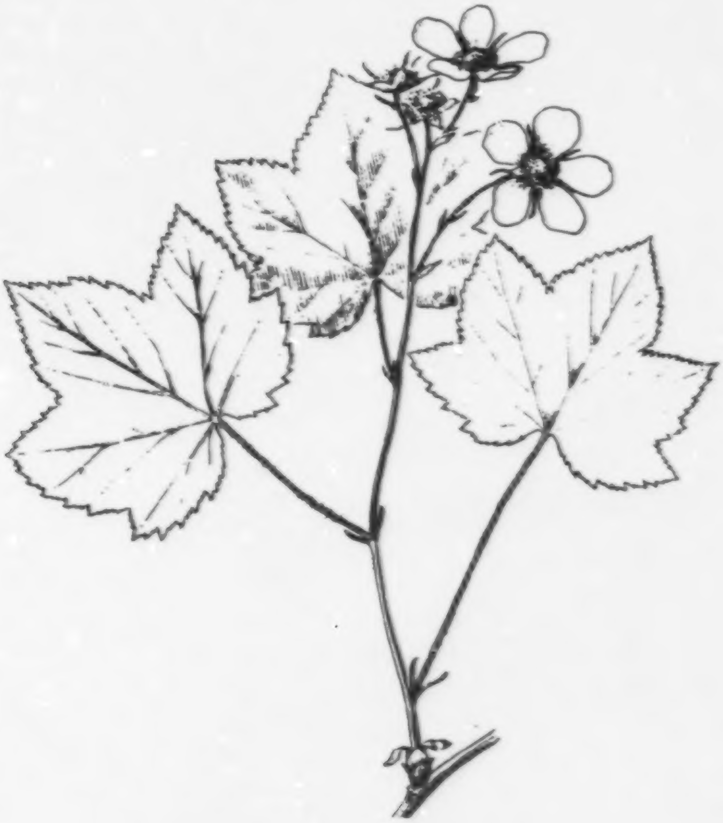
THIMBLEBERRY

Rubus parviflorus

Thimbleberry grows to 2 m in height. Unlike other members of its genus, it does not possess thorns. The leaves are up to 15 cm across, palmately lobed and marginally toothed, with a felt of short hairs on both sides. They superficially resemble maple leaves.

The 1.5 to 2.5 diameter flowers appear from May to July. The 5 petals are white to pinkish-white. Thimbleberry gets its name from its thimble-shaped, raspberry-like berries.

Thimbleberry is usually found in pure stands. The only shrub consistently found in association with it is salmonberry. It is, however, less common than salmonberry. It is found along streams, rivers, and the periphery of swamps. Thimbleberry does not appear to be able to withstand long periods of inundation, and therefore rarely composes the dominant vegetation of habitats characterized by constantly saturated or inundated soils.



Plant Species

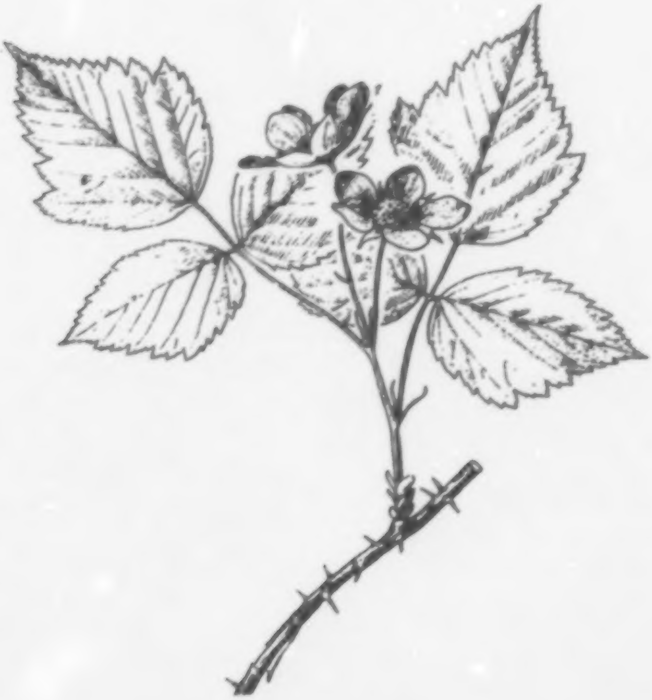
SALMONBERRY

Rubus spectabilis

Salmonberry is a high shrub, often reaching 3 m in height. Old growth stems are somewhat bristly due to the large number of small thorns that cover its surface. New growth possesses few thorns if any. The plant is strongly rhizomatous. The leaves are subdivided into 3 completely separated leaflets that are marginally toothed.

Salmonberry flowers from April to July. The flowers are approximately 2 cm in diameter. The 5 petals are light purple to magenta.

This wild raspberry is a very common shrub along the margins of lakes, marshes, and swamps. It is a common in coniferous forests only along streams and other wet habitats. Salmonberry is an aggressive plant that rapidly establishes dense thickets in optimal environments.



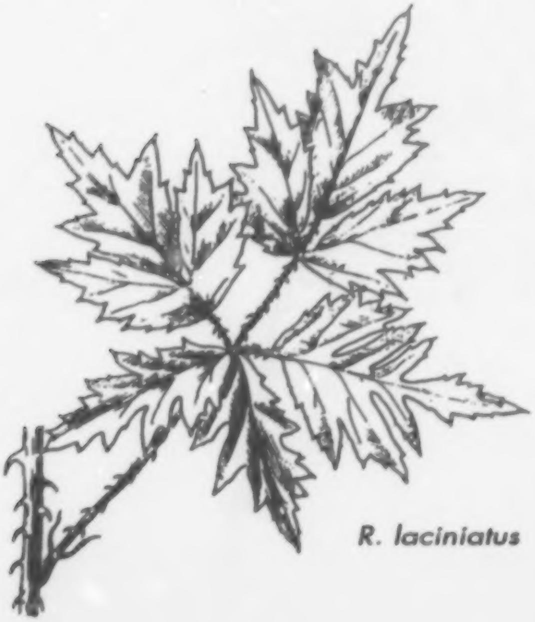
Plant Species

EVERGREEN BLACKBERRY
Rubus laciniatus

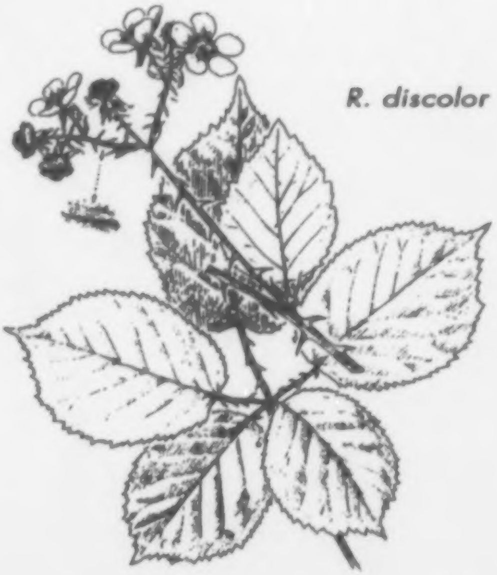
HIMALAYAN BLACKBERRY
Rubus discolor

Both evergreen and Himalayan blackberry have been introduced to North America from Europe. These vines are often mistaken for shrubs. Both species keep their leaves throughout the winter. The blades of evergreen blackberry are divided into five leaflets, some of which are themselves completely divided. The blades of Himalayan blackberry possess three to five leaflets, the margins of which are marginally toothed and not deeply divided. Both plants are extremely thorny. Both species possess flowers that are 5 petalled. Evergreen blackberry flowers are pinkish white, 2 to 2.5 cm in diameter. Himalayan flowers are slightly larger and are white to pinkish white. Both plants produce purplish to black raspberry-like berries that are approximately 1.5 cm in diameter.

Though not specific to riparian habitats and other moist environments, these two blackberries often dominate riparian floral communities. They are highly aggressive species, and once established, slowly choke out native species in all but the wettest habitats.



R. laciniatus



R. discolor

Plant Species

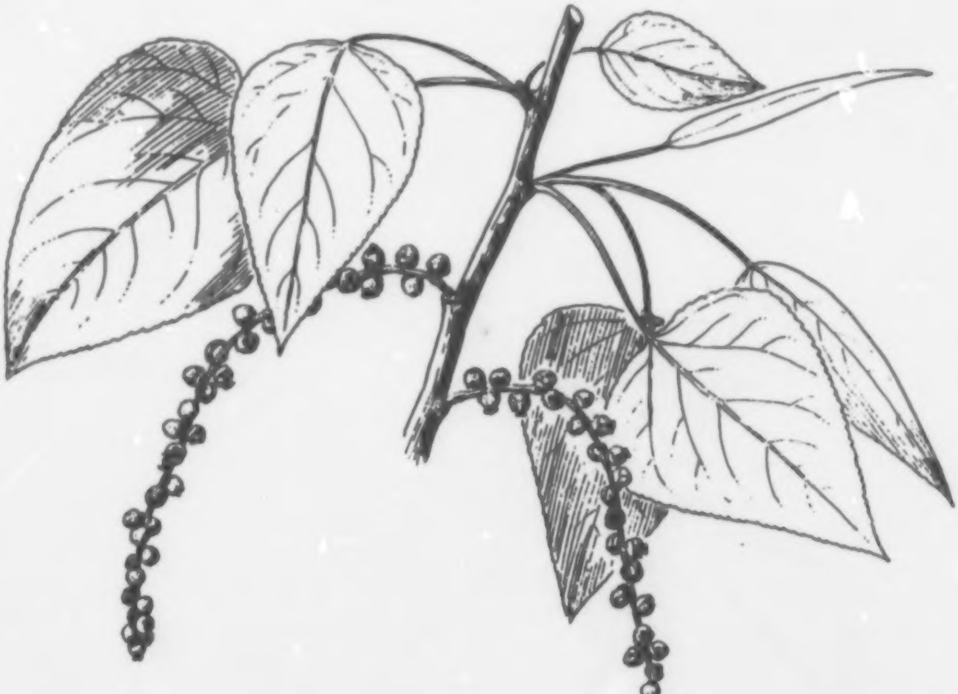
COTTONWOOD

Populus trichocara

Cottonwood may grow to 40 m in height with a trunk diameter of 1.5 m or more. Young trees less than 15 cm in diameter possess bark that is smooth and grey-green to nearly white. As the tree ages, the bark becomes deeply grooved and grey. The leaf buds are protected by distinctive brown scales that are covered with a sticky, fragrant substance. The leaf blades, to 20 cm in length, are widely triangular in shape. The outer margin is finely toothed. The leaves are usually bright green above and brownish-grey and resin stained below.

The pollen-producing and seed-bearing catkins are borne on separate male and female trees respectively. In summer the small ripe fruits split and release their seeds. The seeds are covered with cottony hairs.

Cottonwood is typically found in bottomlands bordering rivers, streams, lakes and marshes. It is often the dominant deciduous tree of such habitats.



Plant Species

QUAKING ASPEN

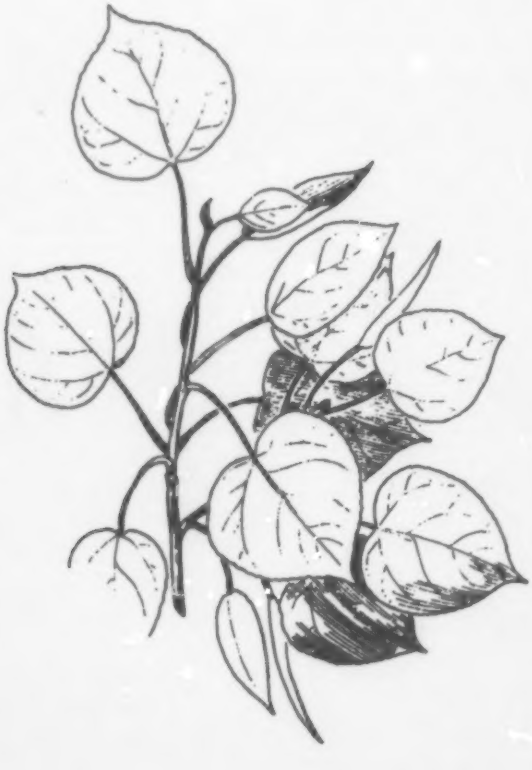
Populus tremuloides

Quaking aspen attains heights of up to 25 m. Its powdery white bark is due to a chalk-like substance that is easily rubbed off. As with cottonwood, its leaves are widely triangular, marginally toothed, and reach lengths of 5 to 6 cm. The petioles are flexible and strongly flattened at right angles to the blades, resulting in the leaves quivering in the slightest of breezes. Unlike cottonwood, the leaf buds are not resinous or fragrant.

Quaking aspen is dioecious, possessing male and female catkins on separate plants.

This tree tends to vegetatively multiply by the growth of suckers projecting from an extensive shallow root system. It often forms pure stands of genetically identical trees.

Quaking aspen is found on the banks of streams and rivers, the margins of lakes and marshes, and moist environments of upland habitats. It is far more common in the central and northeastern areas of British Columbia than on the coast.



Plant Species

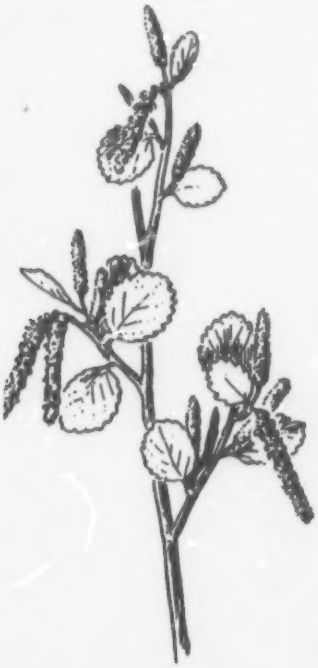
BOG BIRCH

Betula glandulosa

Bog birch is a spreading or erect shrub that grows to 2 m in height. The young branches of this shrub possess a dense covering of resinous wart-like glands and short hairs. The young branches are reddish-brown, while older branches are gray-brown to blackish. The leaves are nearly round, up to 4 cm in length, and marginally toothed with 10 or fewer teeth on each side. The leaves are thick and leathery and glandular on both sides.

Bog birch is monoecious, possessing male and female catkins on the same plant. Mature male catkins are 1 to 2 cm long, while mature female catkins are 1 to 2.5 cm long and 3 to 5 mm thick.

This small birch is typical of stream banks, the margins of lakes, marshes and bogs, and dryer regions along alpine slopes.



Plant Species

WATER BIRCH

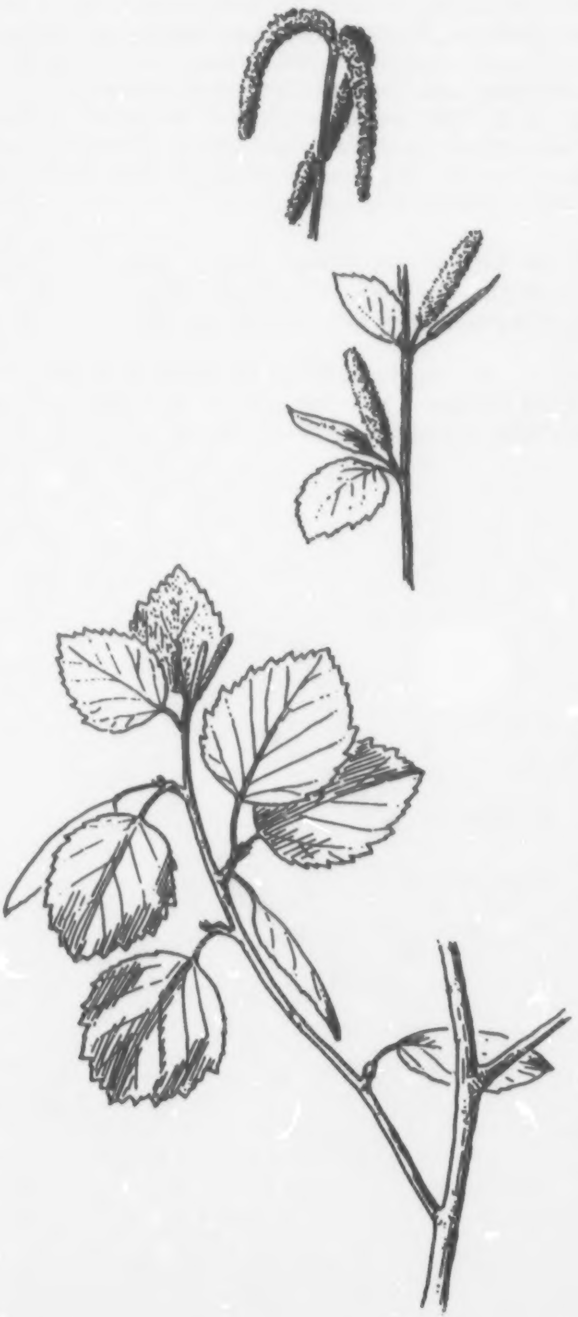
Betula occidentalis

The growth habit of water birch is highly variable. It attains heights as a small tree of 14 m or as a coarse shrub, 3 to 10 m. The bark is dark reddish-brown to black, smooth, with horizontal elongate lenticels. Unlike its very close relative, paper birch, the bark is tight and nonpeeling. Young twigs possess numerous crystalline glands and small hairs. The leaves, 2.5 to 5 cm long, are commonly ovate to almost round with toothed margins. They are often shiny green above and may or may not possess very fine hairs below.

Water birch is monoecious, both male and female catkins occur on the same plant. The female catkin ranges between 2 to 4 cm long and 4 to 10 mm thick and may occur in pairs or singly.

Water birch and paper birch readily hybridize in habitats where they occur together. Some 15 variants of the water X paper birch hybrid complex have been identified. These variants express some characters of both species and some characteristics intermediate between the two. Refer to Hitchcock and Cronquist (1969) for a detailed discussion.

This birch is found on the banks of streams and rivers, the margins of marshes and swamps, and other wet habitats. Its distribution in British Columbia appears to be limited to east of the Coast and Cascade Ranges.



Plant Species

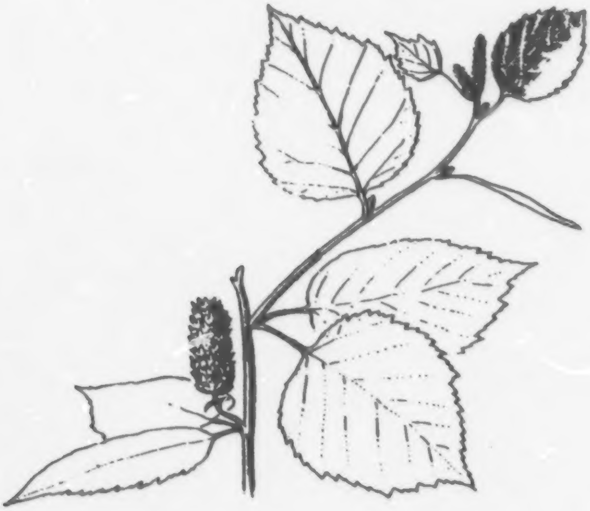
PAPER BIRCH

Betula papyrifera

Paper birch grows to a height of 30 m. It possesses a papery bark, ranging in colour from chalky-white to cherry, that readily peels away in strips. The bark is smooth and marked with conspicuous brown horizontal lenticels. Young twigs have smooth brown bark. The leaves are narrowly ovate to oval to nearly round. They are coarsely toothed along the margins. The leaves are characteristically dull surfaced, the undersides of which possess fine hairs, especially along the veins, and may or may not exhibit minute glands.

Paper birch is monoecious, bearing male and female catkins on the same plant. The female catkin may be borne singly or in pairs, and at maturity attain lengths of 3 to 5 cm.

Paper birch may be found on the banks of streams and rivers, the margins of lakes and swamps, and open to dense moist woods. It is also common in dry, upland habitats.



Plant Species

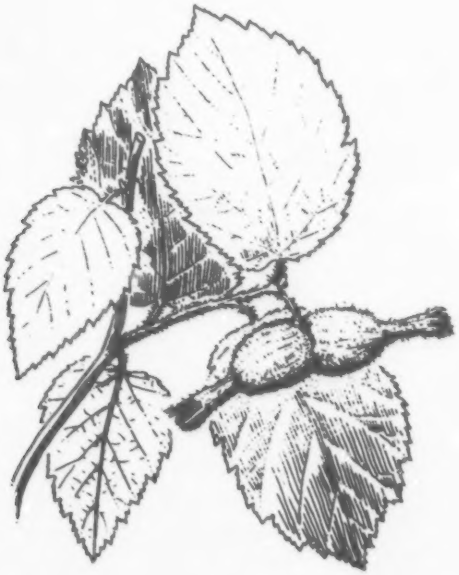
BEAKED HAZEL NUT

Corylus cornuta

Beaked hazel nut is a small shrub 1 to 4 m in height. Its habit varies from densely clumped to broadly colonizing by scattered shoots arising from a widespread rootstock. The leaves are oval to ovate, widest beyond the mid-length. They are 4 to 10 cm long and marginally toothed. Twigs, leaves and bud scales possess white straight hairs.

The male catkins are borne on the ends of branches of the previous growing season. When flowering (early spring before the leaves emerge) the catkins are 4 to 7 cm long. The minute female catkins are contained within the apical bud that will also give rise to a twig and foliage. The buds containing the female catkins occur at the ultimate or near ultimate nodes of the previous growing season. The fruit (nut) is enclosed by two leaves to form a vase-like husk. The leaves extend beyond the nut to give the entire structure a beaked appearance.

Beaked hazel nut is a widespread shrub that grows along streams and rivers and other wetland habitats.



Plant Species

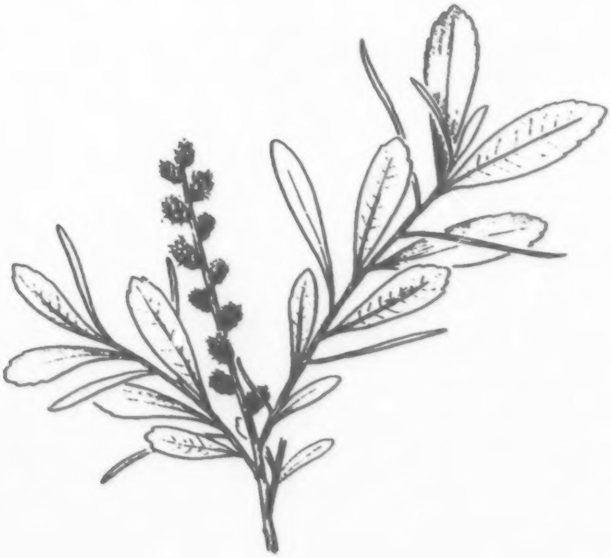
SWEET GALE

Myrica gale

Sweet gale is a small shrub that grows from 10 cm to 2 m in height. The branches are dark reddish-brown to black with fine yellowish horizontally elongated lenticels. The leaves are narrow, tapering at the ends, widest above the mid-length. They possess minute resinous yellow glands.

Sweet gale is commonly dioecious, however, some monoecious plants do occur. The male catkins are 1 to 1.2 cm long. The female catkins are compact and cone-like. In fruit, the female catkins are 1 to 2 cm long.

Sweet gale is found along the margins of lakes and marshes, stream and river banks, and in bogs.



Plant Species

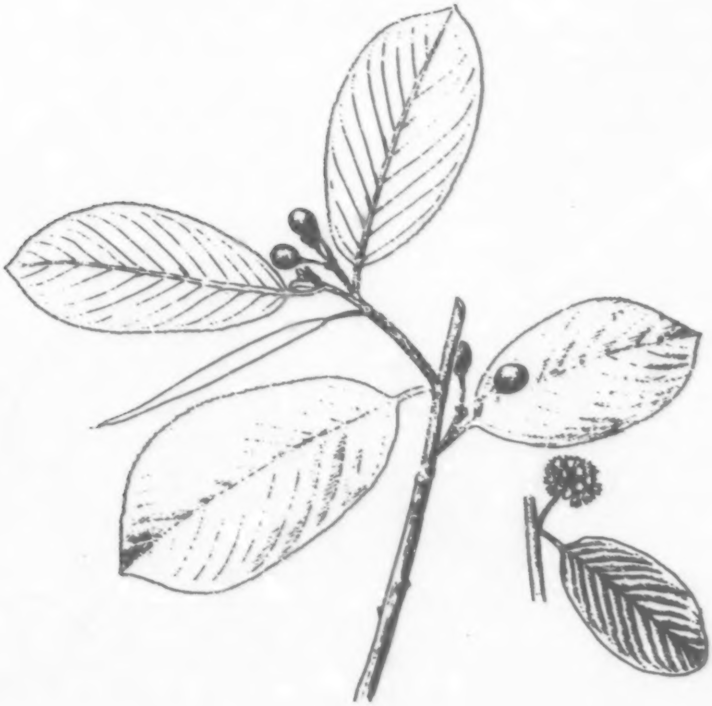
CASCARA

Rhamnus purshiana

Cascara may reach a height of 10 m. The shiny dark green leaves of the tree are 6 to 13 cm long, while the leaf margins are finely toothed. The ovate-oblong leaves bear 10-12 prominent nearly parallel veins on each side of the midrib.

The flowers are small and greenish white. The berries are purplish-black and 6 to 9 mm long. They ripen in late summer.

Cascara does not occur specifically in wet environments. It is a common inhabitant of deciduous and mixed coniferous forests.



Plant Species

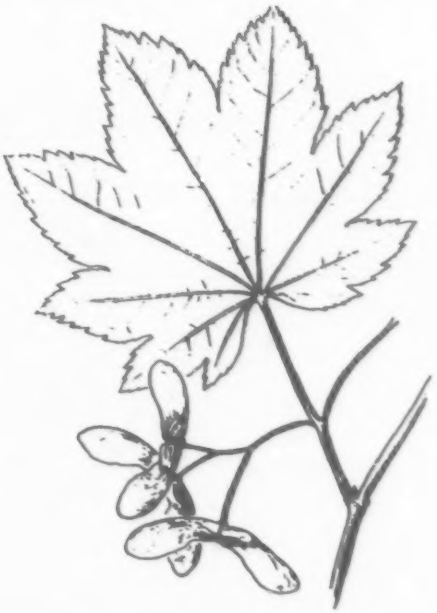
VINE MAPLE

Acer circinatum

This shrub or small tree grows to heights of 1 to 8 m. Vine maple often has several principal trunks. The trunks rarely exceed 15 cm in diameter. The bark of young branches is smooth and pale green. The bark of older branches and trunks is often a dull gray. In shady habitats, the lower branches creep along the ground for some distance before they reach more light and turn upward. This habit allows for vegetative propagation through layering. The leaves are bright green, 10 cm across, and divided by 7 to 9 clearly cut lobes. The leaves are marginally toothed.

Vine maple flowers are small and borne in small clusters. The one seeded, wing bearing fruits are borne in pairs. The fruits are wide spreading and form a propeller-like structure.

Vine maple is found mixed with conifers throughout coastal southern British Columbia. It is highly tolerant of shade. It is found along the banks of streams and rivers, the margins of lakes and marshes, and moist woods.



Plant Species

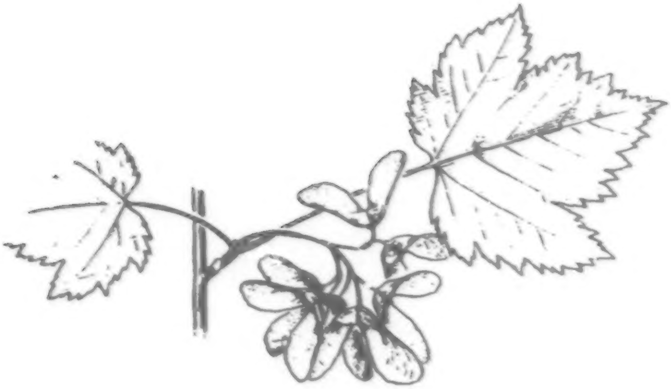
DOUGLAS MAPLE

Acer glabrum

The Douglas maple occurs as a shrub or small tree 1 to 10 dm in height. The bark on the main trunk is greyish-brown. New twigs and petioles are bright red. The leaves are 3- to 5-lobed, marginally toothed, and 2 to 14 cm across.

Douglas maple flowers are small (8 mm across) and borne in small clusters. The one seeded, wing bearing fruits are born in pairs 2.5 to 3 cm long. They form a wide v shaped configuration at or slightly less than 90 degrees to one another.

Douglas maple is found inhabiting a wide range of habitats. It is especially common in the southern half of the province east of the Cascade Range.



Plant Species

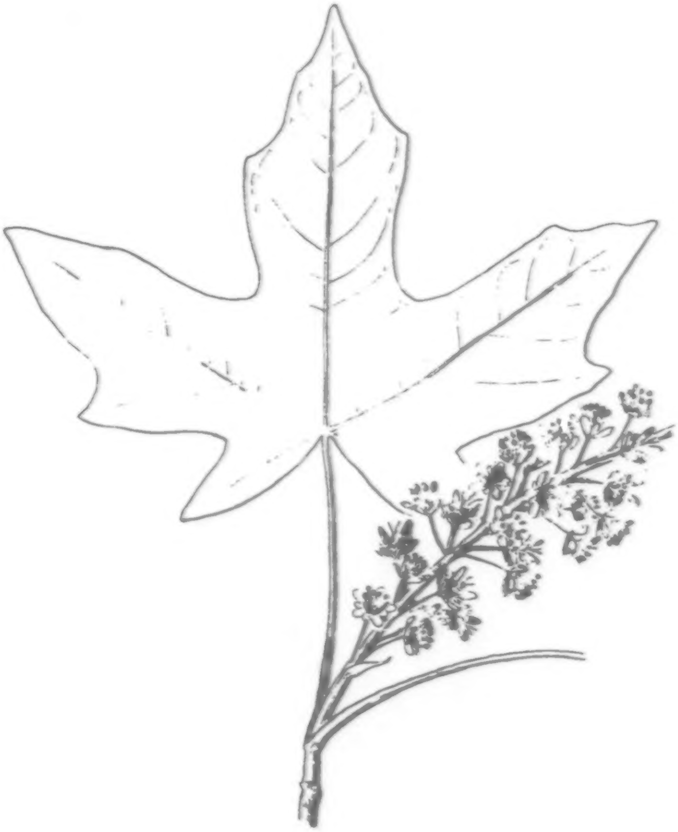
BROAD-LEAF MAPLE

Acer macrophyllum

This large spreading tree grows to 30 m in height. The trunk may exceed 1 m in diameter. The bark is greenish-grey on the branches to a drab grey-brown with narrow ridges on the trunk and old large branches. The leaves are 10 to 30 cm across. They are deeply lobed into five primary sections. The leaves turn a pale yellow in the fall.

The greenish-yellow flowers occur in drooping clusters. They appear with or soon after the emergence of the leaves in early spring. The one seeded, wing bearing fruits are borne in pairs. Each are 3 to 4 cm long. They form a v-shaped configuration at 45 to 60 degrees to one another.

This large maple is found in moist, mixed coniferous forests west of the Cascade Range.



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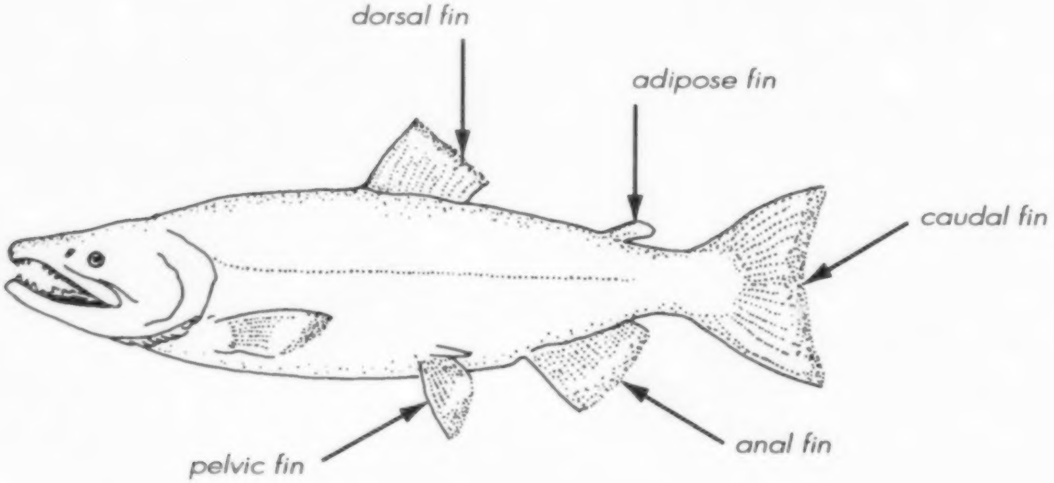
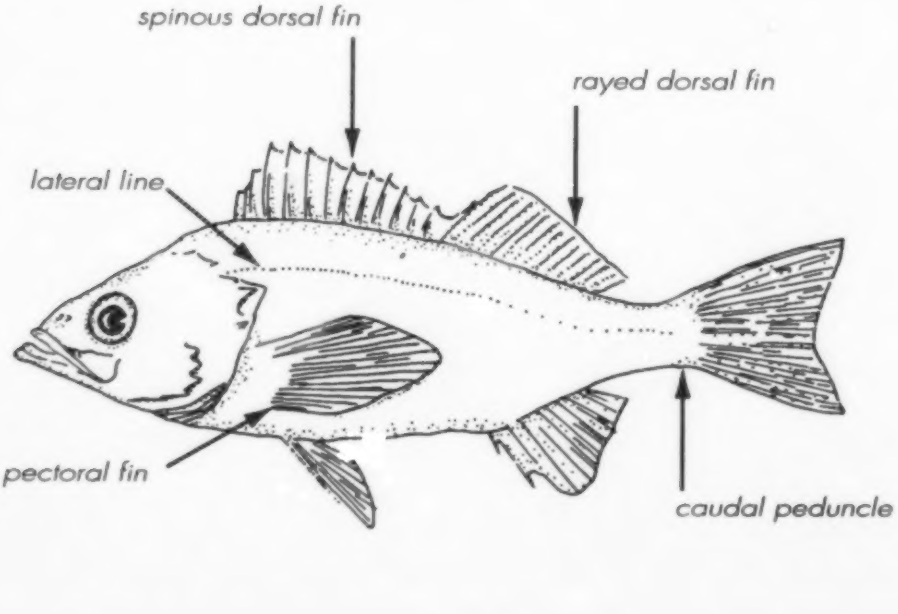
APPENDIX 4 *Fish and Crustaceans*

Introduction

The following descriptions are restricted to those commercial and recreational fishery species that benefit most from habitat enhancement techniques described within this manual. For the five species of salmon, descriptions have been restricted to juveniles and spawners, as descriptions for ocean adults are presented in Chapter 1. Length and weight information for spawners is omitted as it varies significantly between races and different year classes.

General External Anatomy – Fish


dorsal fin
adipose fin
caudal fin
anal fin
pelvic fin

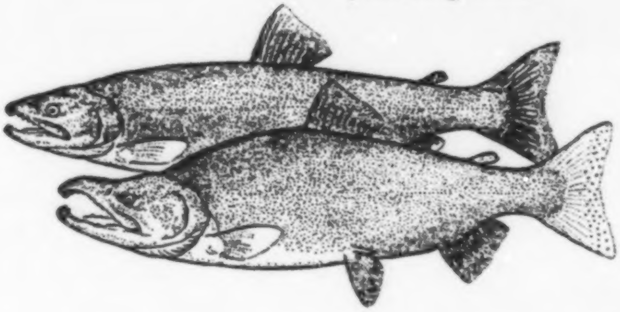

spinous dorsal fin
rayed dorsal fin
lateral line
pectoral fin
caudal peduncle

Salmonids

Sockeye Salmon
Oncorhynchus nerka

Spawners

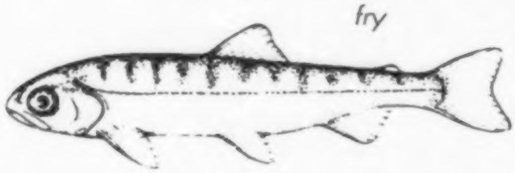
Female	head green; forward dorsal surface forms a hump; body red
Male	head green; forward dorsal surface forms a hump; body red



spawning adults

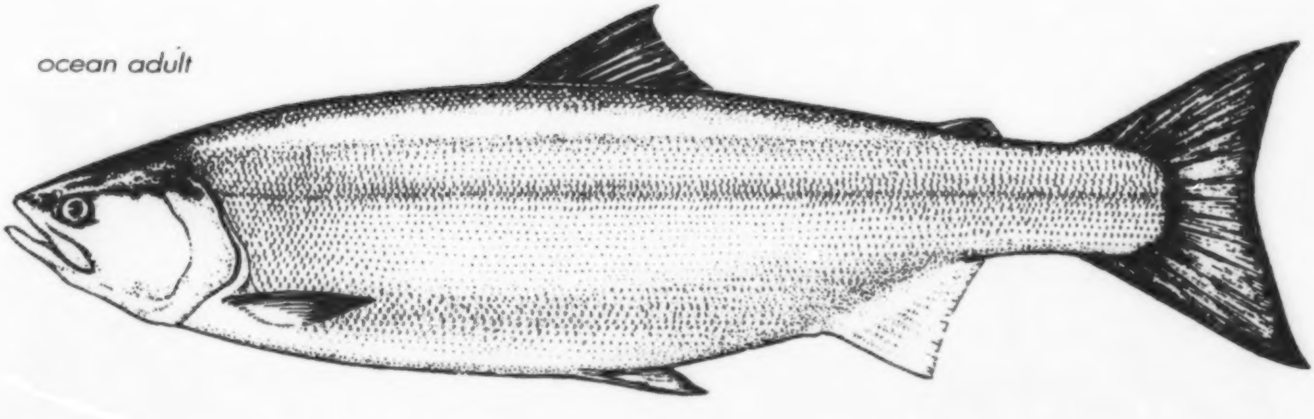
Juveniles

Fry	length 2-3 cm; green back; parr marks short, oval and mainly above the lateral line
Smolt	length 6-13 cm; dorsal surface brown or green; parr marks small, irregular and faint or absent; ventral surface silver



fry

ocean adult

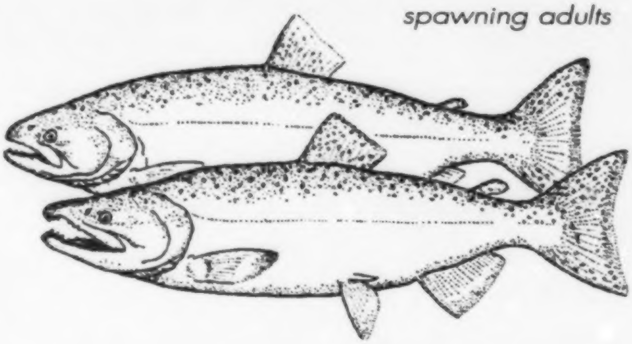


Salmonids

Chinook Salmon
Oncorhynchus tshawytscha

Spawners

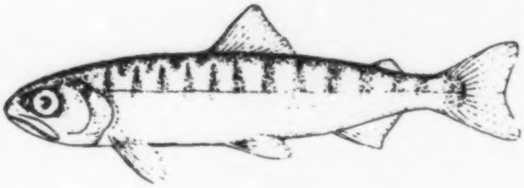
Female	body dark; irregular black spots on back, upper sides, dorsal fin and both lobes of caudal fin
Male	forward part of body may deepen considerably; irregular black spots on back, upper sides, dorsal fin and both lobes of caudal fin



spawning adults

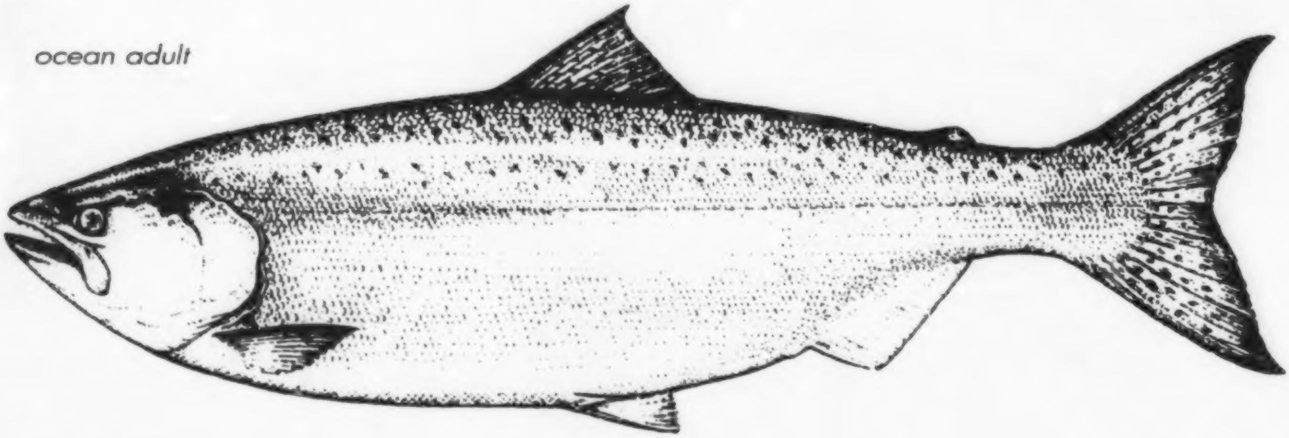
Juveniles

Fry	length 4-8 cm; dorsal fin with dark leading edge and white tip; adipose fin with dark trailing edge; parr marks prominent, longer than vertical diameter of eye; dark areas along lateral line equal to or greater than light areas; anal and pelvic fins with white leading edges
Smolt	length 8-10 cm; much like fry, parr marks becoming less prominent to completely absent



fry

ocean adult



Salmonids

Pink Salmon
Oncorhynchus gorbuscha

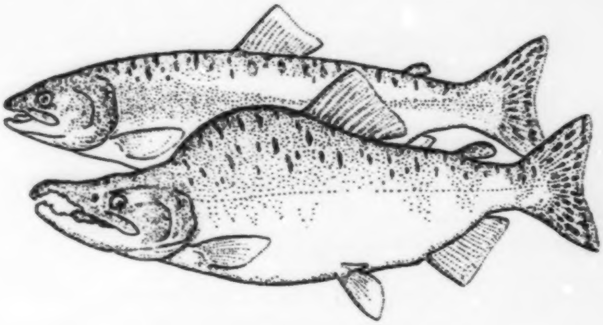
Spawners

Female	numerous large black, oval spots on upper sides, back and both lobes of caudal fin; dark stripe on sides of body; ventral surface glaring white
Male	forward dorsal surface forms a prominent hump; body spots present; broad, dark stripe on side; caudal fin spotted; ventral surface glaring white

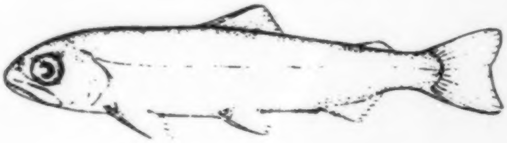
Juveniles

Fry	length 3-3.5 cm; no parr marks; dorsal surface dark green; ventral surface and sides silver
Smolt	length 3.5-10 cm; similar to fry

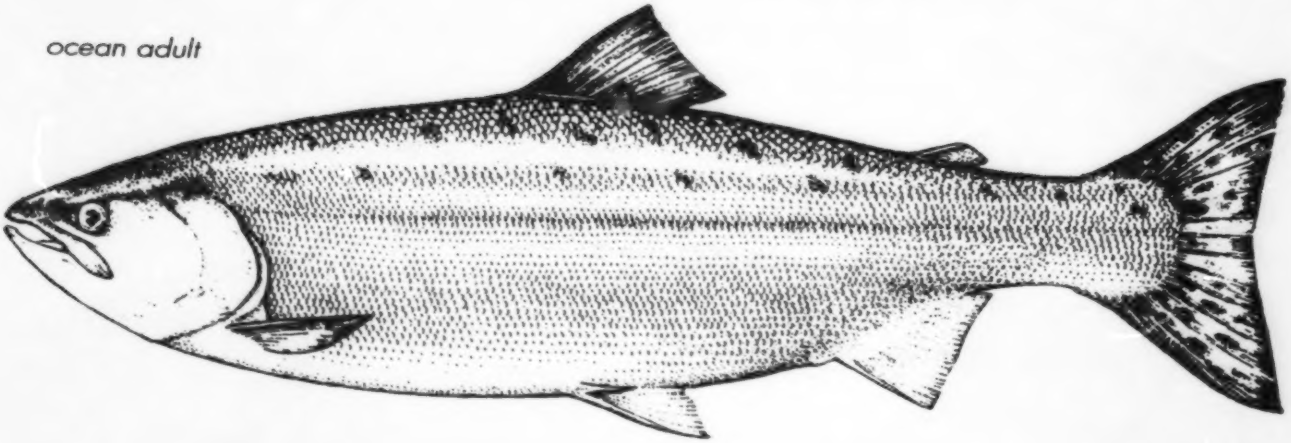
spawning adults



fry



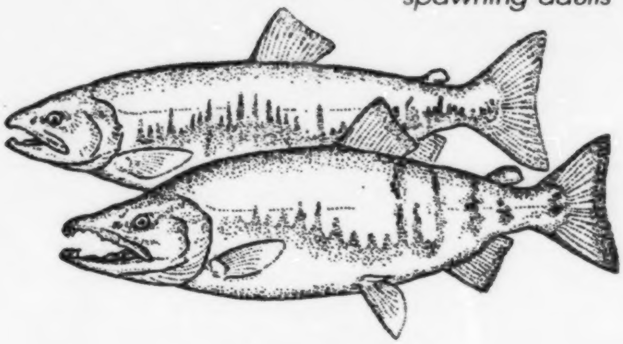
ocean adult



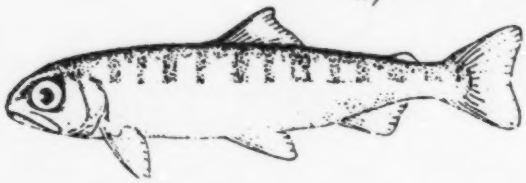
Salmonids

Chum Salmon
Oncorhynchus keta

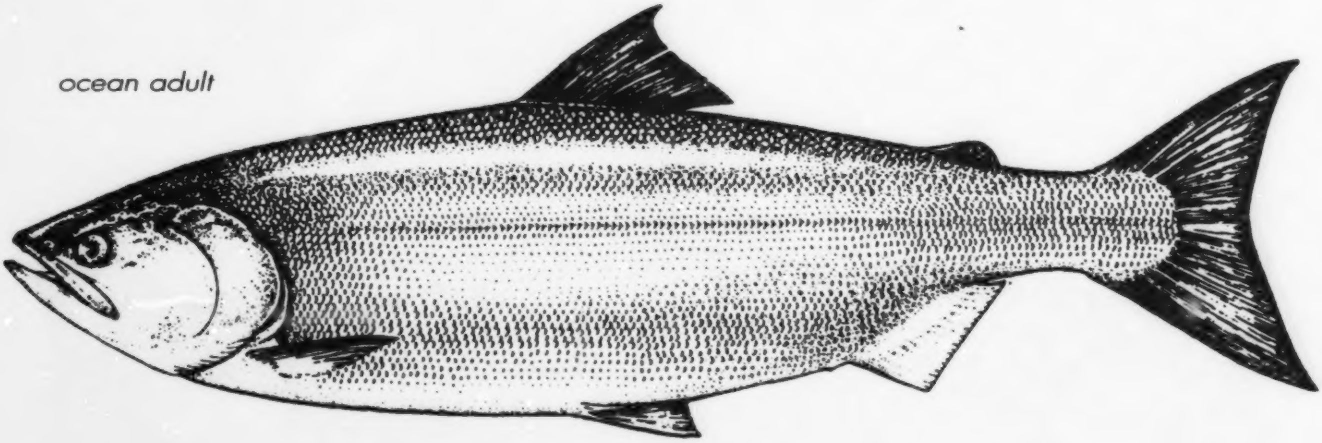
Spawners	
Female	body spots absent; side of body bears broad, dark purple stripe
Male	body spots absent; side of body bears vertical patterns of black, yellow and purple; prominent teeth
Juveniles	
Fry	length 3.0-6.5 cm; slender parr marks above lateral line; dorsal surface dark green; ventral surface and sides silver
Smolt	similar to fry, however, without parr marks; 5.0-10.0 cm



spawning adults



fry



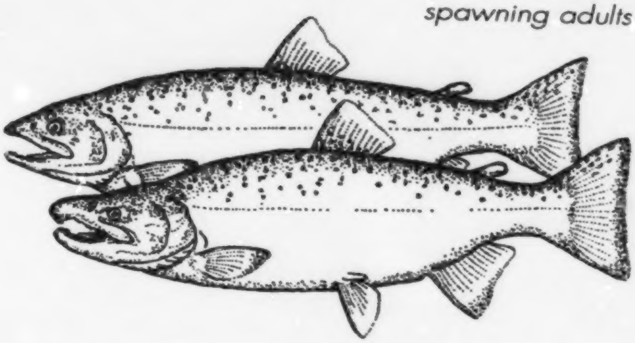
ocean adult

Salmonids

Coho Salmon
Oncorhynchus kisutch

Spawners

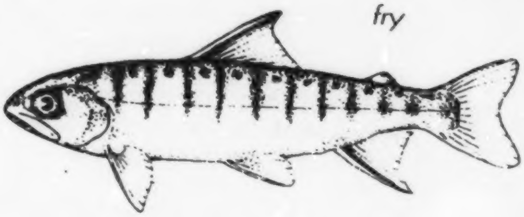
Female	*nostrils white; body colour very dark; black spots on back and upper lobe of caudal fin; broad red lateral stripe*
Male	*nostrils white; body colour very dark, side of body with broad, red stripe; caudal fin spotted on upper lobe only*



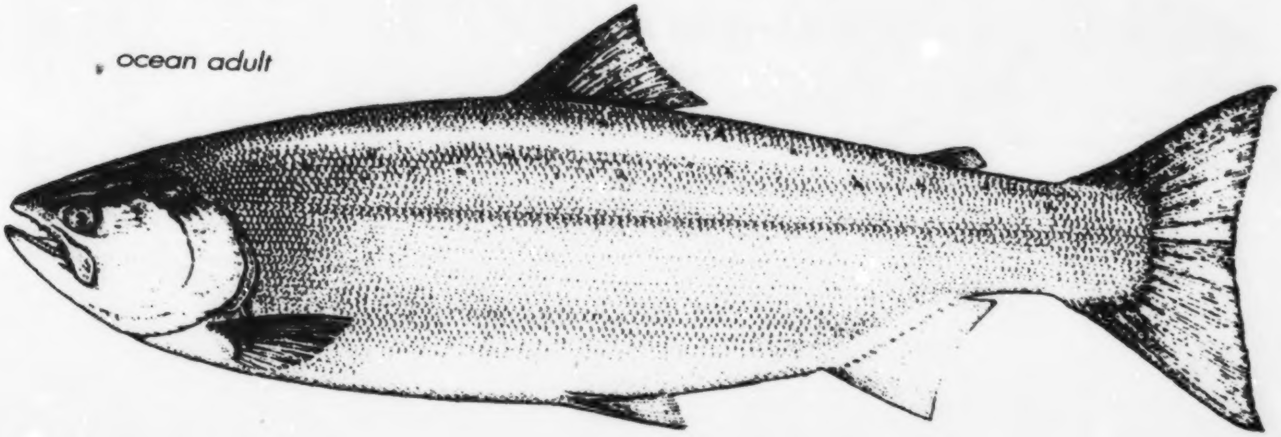
spawning adults

Juveniles

Fry	early-length 3-4 cm; dorsal fin with conspicuous white leading edge followed by dark stripe; parr marks prominent, above and below lateral line; anal fin with extended tip, and white leading edge followed by dark stripe late-length 5-8 cm; dorsal fin with black leading edge and white tip; parr marks prominent; anal fin with extended tip and white leading edge
Smolt	length 8-13 cm; dorsal surface brown or green; dorsal fin with white tip and dark patch; parr marks faint or absent; caudal fin with dark patch at tip of each lobe; anal fin slightly extended, with white tip; ventral



fry



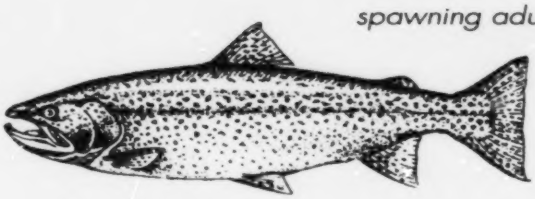
ocean adult

Salmonids

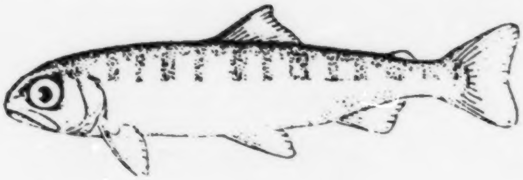
Cutthroat Trout
Oncoryhnchus clarki clarki

Adult	
	body spots abundant both above and below lateral line; greenish blue on back; caudal fin spotted; red dash along inner edge of lower jaw
Juveniles	
Fry	length 2-4 cm; parr marks prominent; dorsal fin spotted with white tip on three rays; adipose fin with dark edge; white leading edges on anal and pelvic fins
1 year +	length 4-22 cm; body spots abundant; spotting below lateral line, equally heavy on anterior and posterior halves of body; dorsal fin spotted with white tips over three rays; caudal fin spotted; anal and pelvic fins with white tips; parr marks may be present

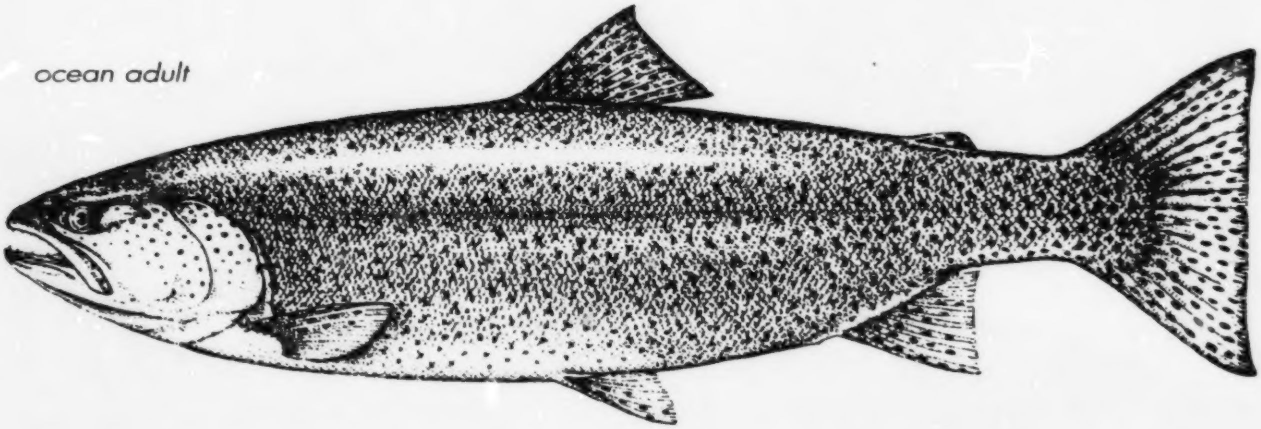
spawning adults



fry



ocean adult

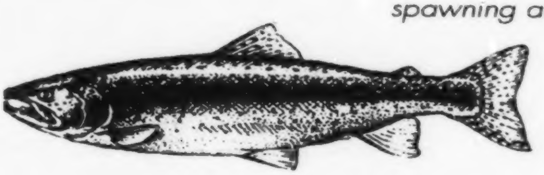


Salmonids

Steelhead (Rainbow) Trout
Onchorhynchus mykiss

Adult

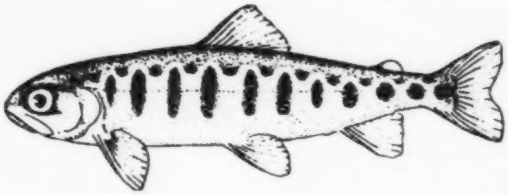
metallic blue on dorsal surface; silvery on sides; black spots on back, dorsal and caudal fins; dorsal, anal and ventral fins with white to orange tips; opercula pink; red band on side of body (more pronounced in mature, spawning fish)



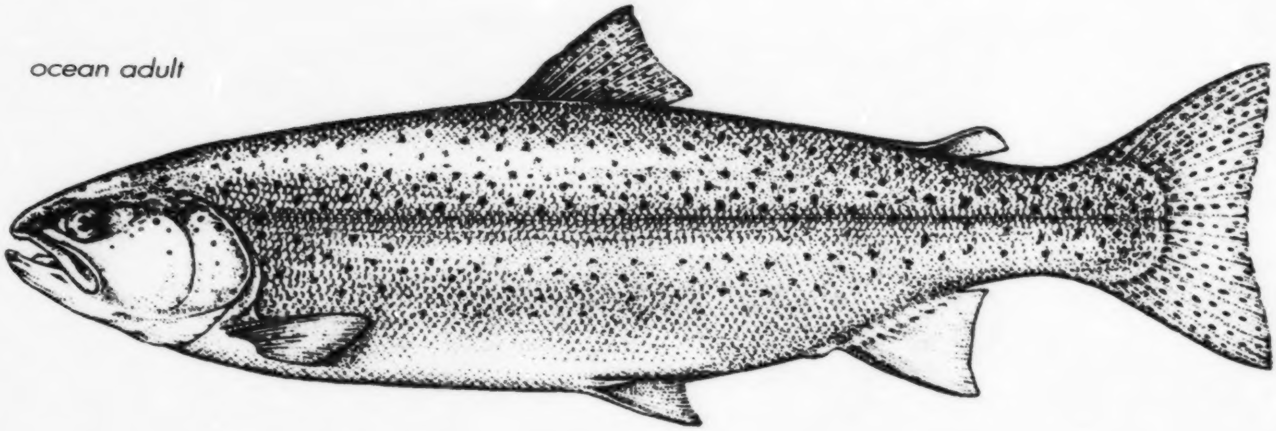
spawning adults

Juveniles

Fry	length 2-6 cm; forward dorsal surface with parr-like marks; parr marks prominent; dorsal fin spotted with white tip on six rays; adipose fin with continuous dark edge; white leading edges on anal and pelvic fins
1 year +	length 6-15 cm; body spots abundant; dorsal fins spotted with white tip over 6 rays; caudal fin spotted; anal and pelvic fins with white tips; pink or red strip on side of body; parr marks may be present



fry



ocean adult

Salmonids

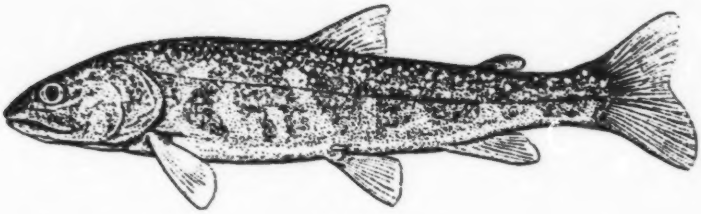
Dolly Varden Char
Salvelinus malma

Adult

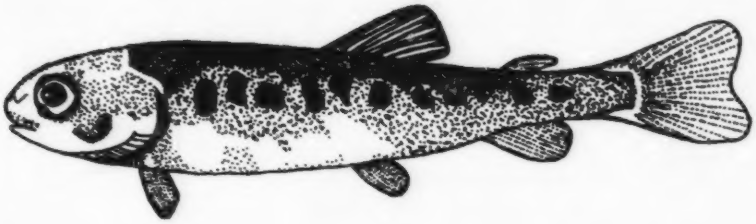
dorsal and upper sides olive-green to brown; sides paler (bright red on spawners); dorsal surface and sides marked with yellow, orange, or red spots; spots usually smaller than the pupil of the eye; dorsal surface sometimes with vermiculations; pelvic and anal fins with cream leading edges

Juveniles

Fry	length 2-7.5 cm; 8-12 irregular, dark parr marks which are mere dark blotches on fish less than 7.6 cm; lower sides with fine dark speckling; dorsal and adipose fins dusky but without spots
1 year +	length 5-23 cm; parr marks may be present but otherwise approaching adult coloration



adult



fry

Salmonids

Arctic Char
Salvelinus alpinus

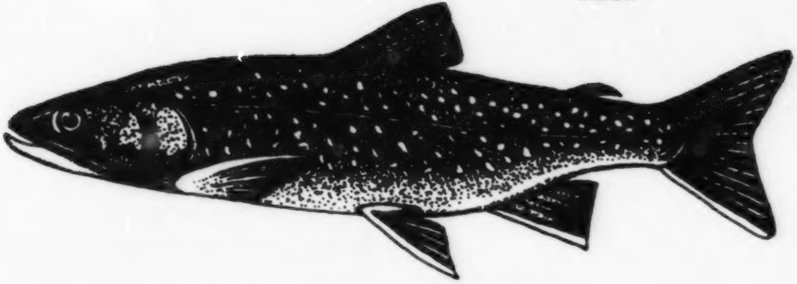
Adult

the backs of anadromous males entering fresh water are often dark green or blue-green, the side silvery blue with scattered orange or red spots, and the belly whitish, or a brilliant orange-red may suffuse the sides and extend across the belly; some fresh water populations may exhibit coloration as previously described or may be silvery with dark green backs; dorsal and caudal fins usually dusky; anal, pectoral and pelvic fins usually light (all lower fins a brilliant hue during spawning); the leading edges of pectoral, pelvic, anal, and sometimes caudal fins, have a bright white margin

Juvenile

sizes of juveniles as well as mature fish highly variable; small char have 10-15 irregularly arranged oval parr marks on sides and closely resemble young juvenile Dolly Varden char

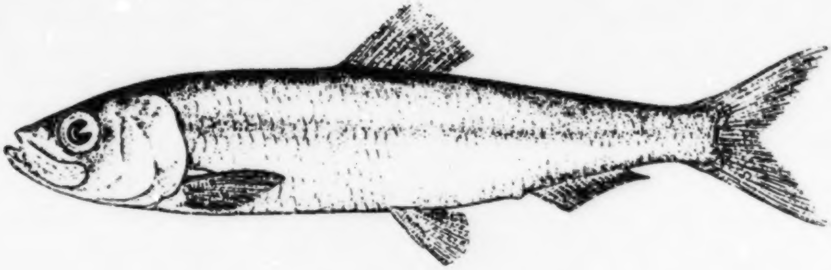
adult



Herring

Pacific Herring
Clupea harengus pallasi

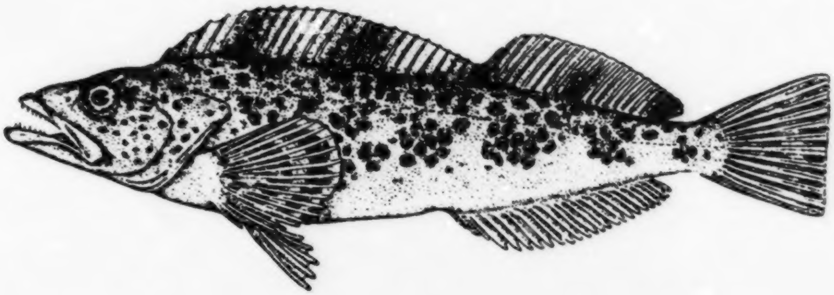
length to 33 cm; bluish green to olive dorsally, silvery along the sides; compressed body, belly possesses keel of scutes; 1 short dorsal fin near the middle of the back; no adipose fin; no fin spines



Lingcod

Lingcod
Ophiodon elongatus

length to 152 cm; gray to brown or green or bluish dorsally, with darker or lighter spotting depending on its environment, paler ventrally; dorsal fin long, spinous and soft-rayed parts separated by a deep notch; mouth exceptionally large, upper jaw extends past eye; teeth large; 3 spines in anal fin



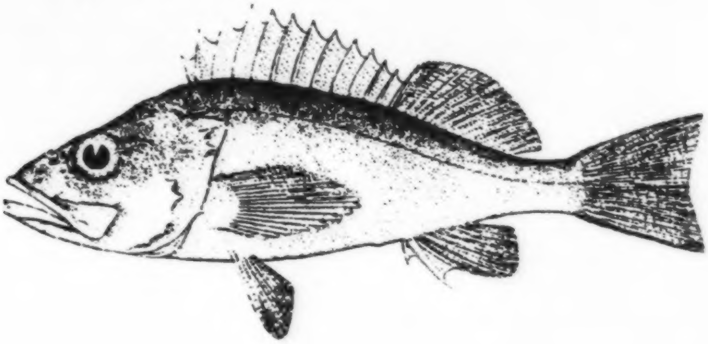
Rockfish

Rockfishes are bass-like, with a more or less compressed body and large mouth. The head and cheeks are usually spiny. The dorsal fin is continuous, with 12-15 spines in *Sebastes* and 13 or more spines in *Sebastolobus*, and 9-16 soft rays. The anal fin has 3 spines and 5-9 soft rays.

Identification is for adults. Species are most easily identified by colour, so emphasis is on coloration and pattern. Descriptions focus on more abundant coastal shallow water species.

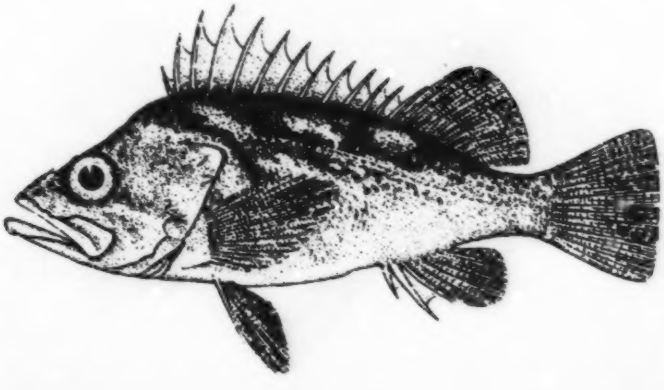
Silvergray Rockfish
Sebastes brevispinus

length to 71 cm; green or gray on back and silver on sides, white ventrally; mouth large, chin projects strongly; ventral surface, anal, pelvic, and pectoral fins tinged with red or pink; lips black



Copper Rockfish
Sebastes caurinus

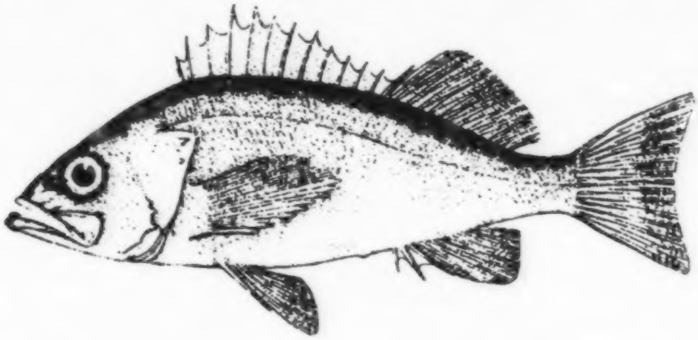
length to 57 cm; dark or olive brown washed with copper-pink, sometimes with yellow patches, white ventrally; usually 2 orange-copper bands radiate backward from eye; pale stripe along lateral line and vague bars behind head; cheek sometimes yellowish; fins copper-black and dusky



Rockfish

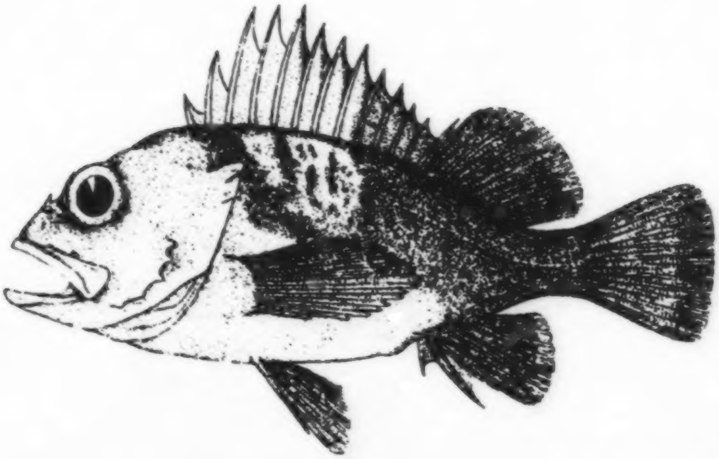
Yellowtail Rockfish
Sebastes flavidus

length to 66 cm; olive to greenish brown or dark gray dorsally, paler ventrally; light patches often occur on upper back; reddish brown speckles on scales; caudal fin dirty yellow; other fins tinged with yellow



Quillback Rockfish
Sebastes maliger

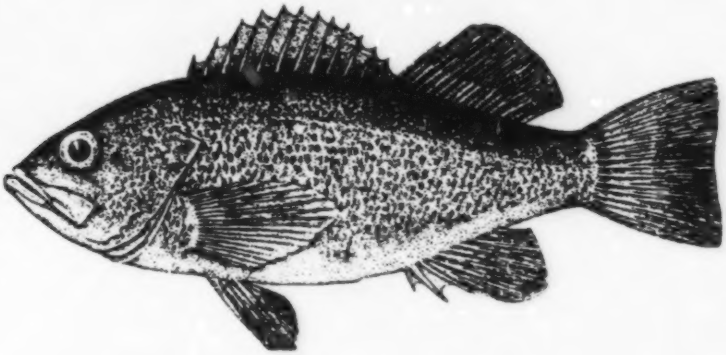
length to 61 cm; brown to black, large mottled patches predominantly on back; orange-brown spots on light tan to orange lower anterior body and head; pectoral and pelvic fins brown to blackish; dorsal fin dark except for yellow streak; dorsal fin spines very long, membrane between spines deeply notched



Rockfish

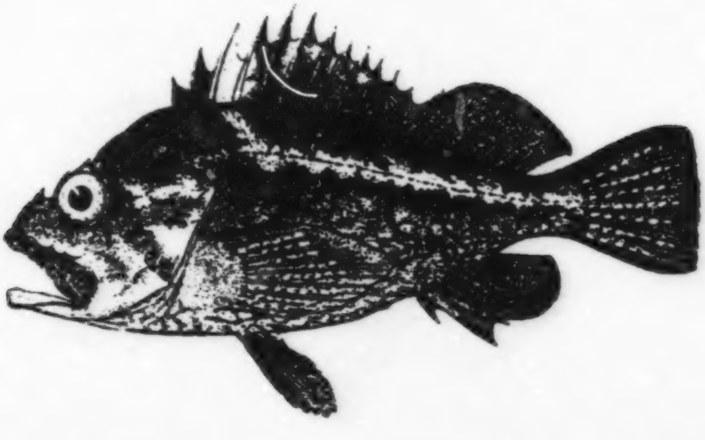
Black Rockfish
Sebastes melanops

length to 60 cm; black to bluish-black on back with mottled gray with black on sides, dirty white ventrally; lighter patches and gray stripes along lateral line often present; many black spots on back extending onto lower spinous dorsal fin; all fins dark



China Rockfish
Sebastes nebulosus

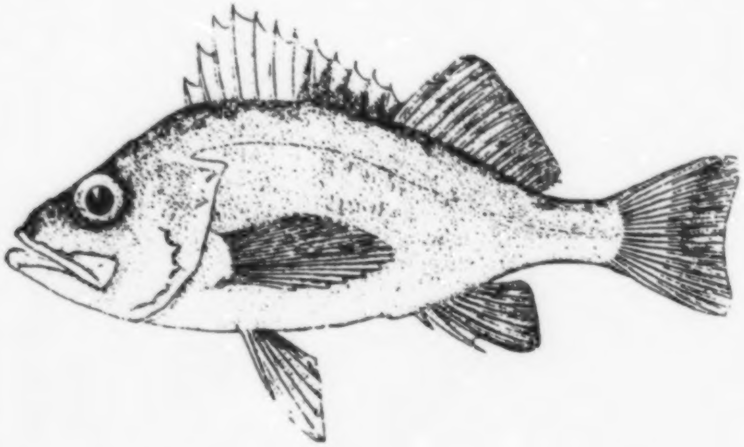
length to 43 cm; black to bluish black mottled with yellow or white, more white ventrally; usually a broad yellowish stripe commencing dorsally at 3rd or 4th spine down medially and along the lateral line to the caudal fin; fins blue-black



Rockfish

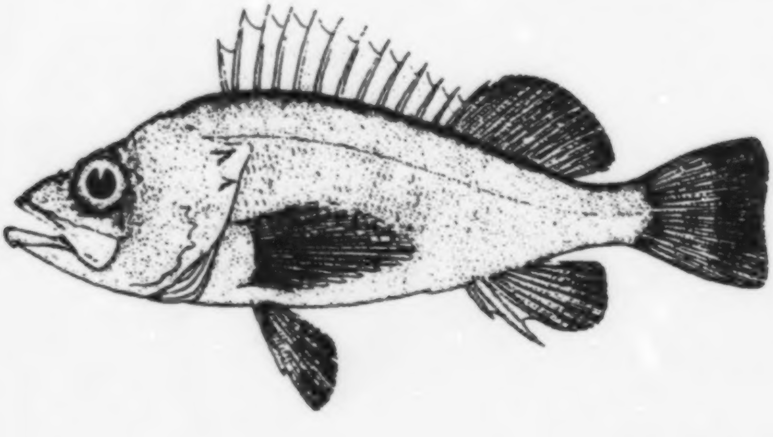
Canary Rockfish
Sebastes pinniger

length to 76 cm; orange on gray or yellow on orange, paler ventrally; fins bright orange; dark blotch on posterior part of spinous dorsal fin; gray zone along lateral line



Yelloweye Rockfish
Sebastes ruberrimus

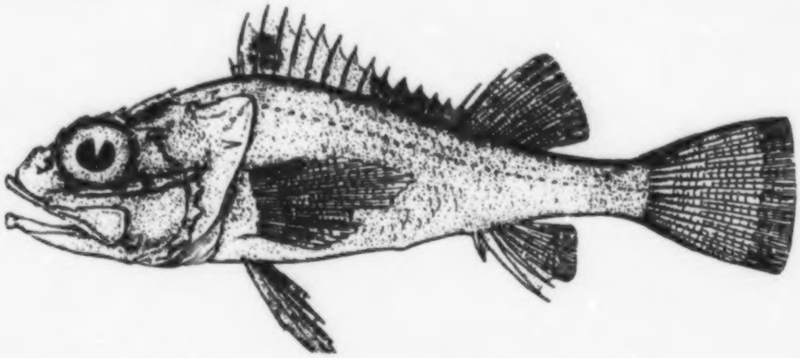
length to 91 cm; eye bright yellow; orange-yellow washed with pink on back and sides; fins pink, usually black on tips, and in large individuals black mottling on head; juveniles have a light stripe along the whole lateral line to the base of the caudal fin where it divides at right angles to encompass the caudal peduncle and a second stripe that starts from immediately below the eye to below the dorsal rays; the second stripe disappears in young adults; lateral stripe disappears in very large individuals



Rockfish

Shortspine Thornyhead
Sebastolobus alascanus

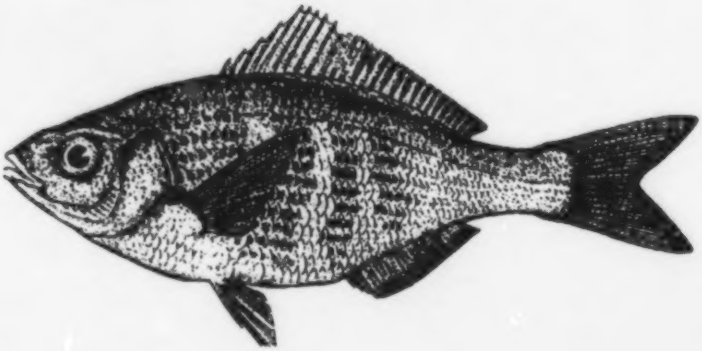
length to 75 cm; brilliant red or pink with dusky patches on body and fins; some black on fins, usually 1 or 2 black blotches on membranes of dorsal fin; head is very spiny
Surfperch are perchlike, compressed, elliptical to oblong fishes; dorsal fin unnotched usually with 9-11 spines, 19-28 soft rays; anal fin with 3 spines and about 15-35 soft rays; caudal fin forked.



Surfperch

Shiner Surfperch
Cymatogaster aggregata

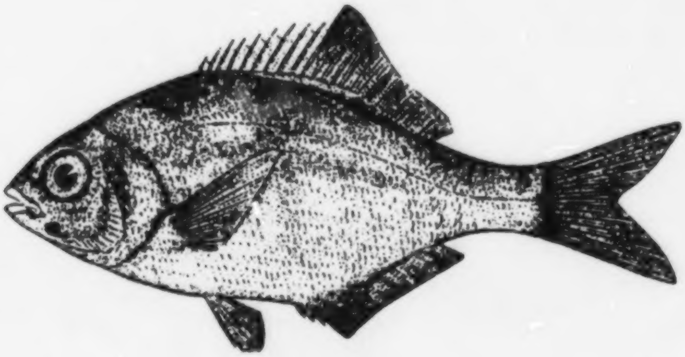
length to 18 cm; silvery with rows of dark spots on scales that form dark stripes on sides; darker or greenish dorsally; broken dark stripes usually crossed by 3 yellow bars on both sides of the body; males usually possess yellow bars in winter and are generally darker in summer; a dark spot is often present above the lip



Surfperch

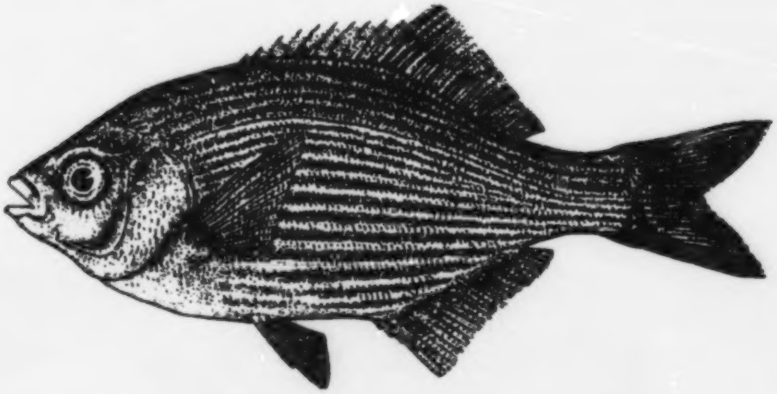
Pile Surfperch
Rhacochilus vacca

length to 44 cm; blackish, gray, or brownish dorsally, silvery below; usually a broad dark bar at midside; often a dark spot below eye; rays at front of soft dorsal fin long, about twice as long as dorsal spines; caudal fin deeply forked; fins dusky

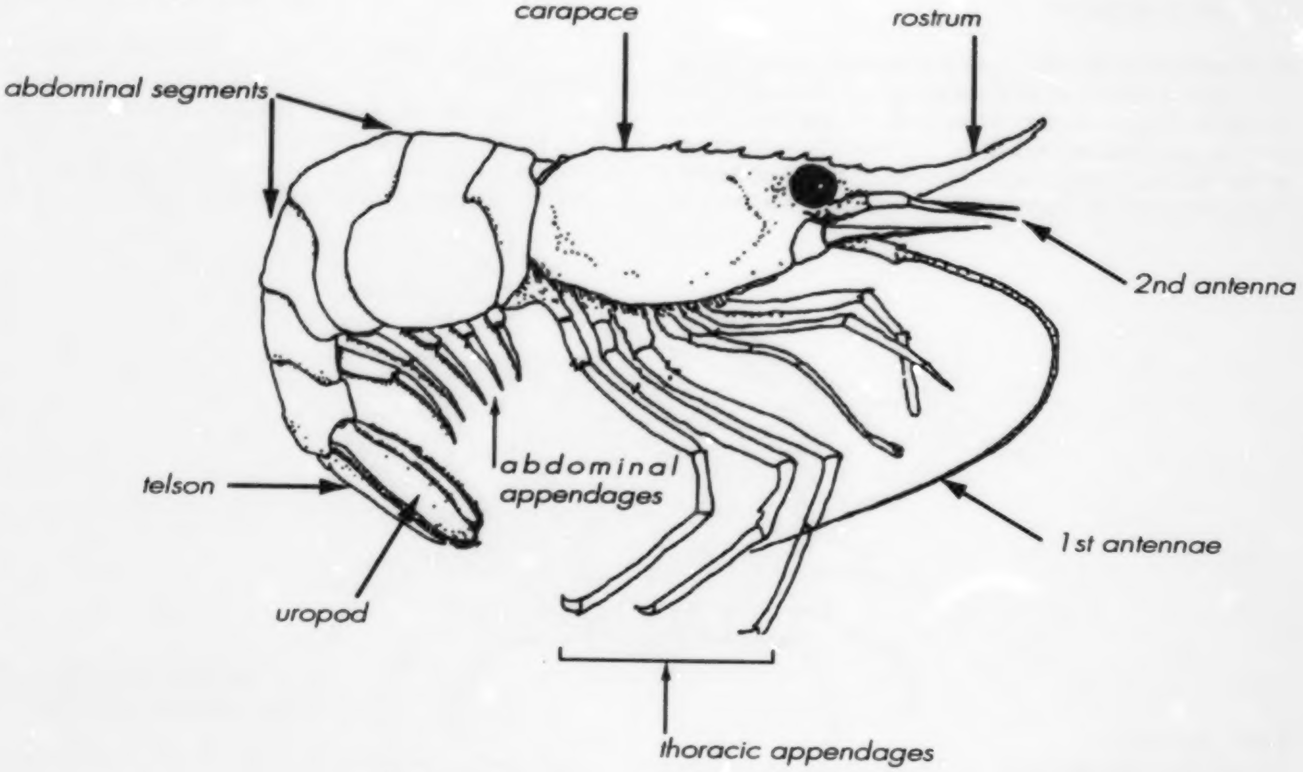


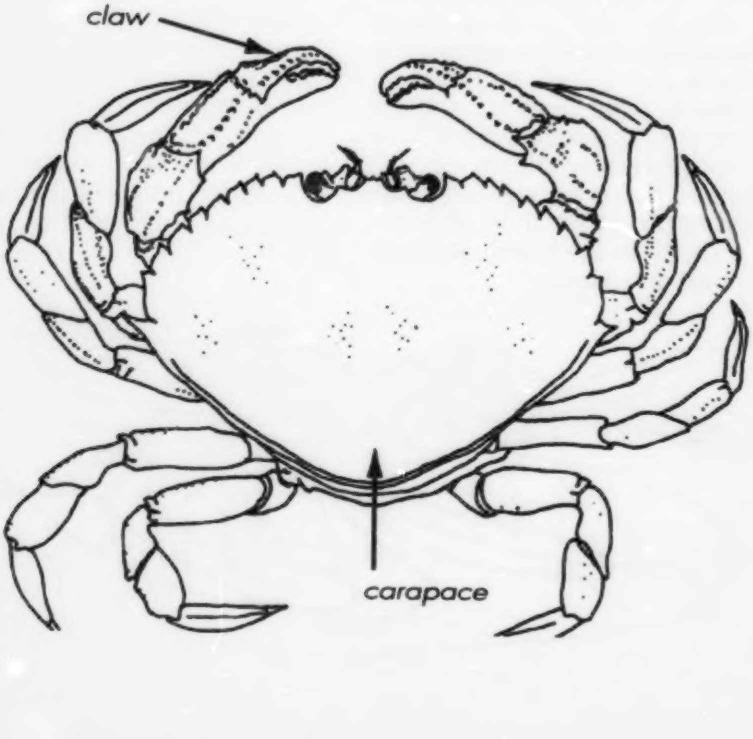
Striped Surfperch
Embiotoca lateralis

length to 38 cm; reddish-orange to copper-brown with about blue stripes below lateral line; brilliant blue streaks and spots on head and gill cover, upper lip often black; middle dorsal spines about one-half the length of the soft rays; fins coppery



General External Anatomy – Crustaceans

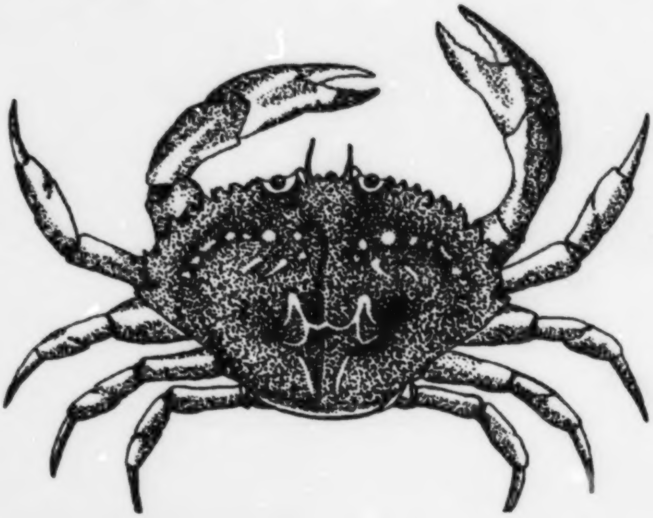

carapace
rostrum
abdominal segments
2nd antenna
abdominal appendages
telson
1st antennae
uropod
thoracic appendages


claw
carapace

Crustaceans

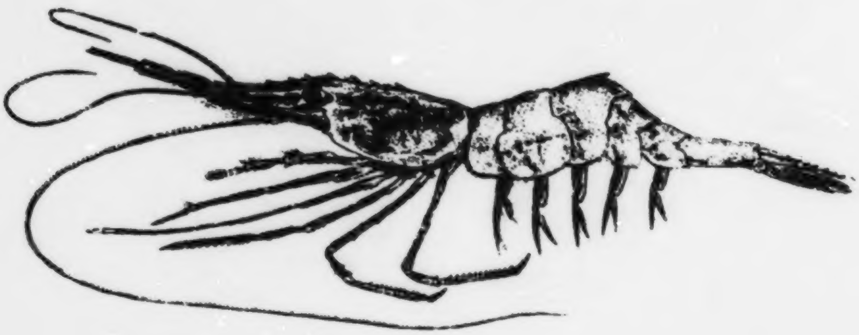
Dungeness Crab
Cancer magister

carapace width to 20 cm; on the front edge of the carapace, starting at the widest point of the body to the midpoint between the eyes, there are 10 distinct, serrated projections with tenth projection at the widest point; most other cancer crabs are widest at the eighth or ninth projection



Pink Shrimp
Pandalus borealis

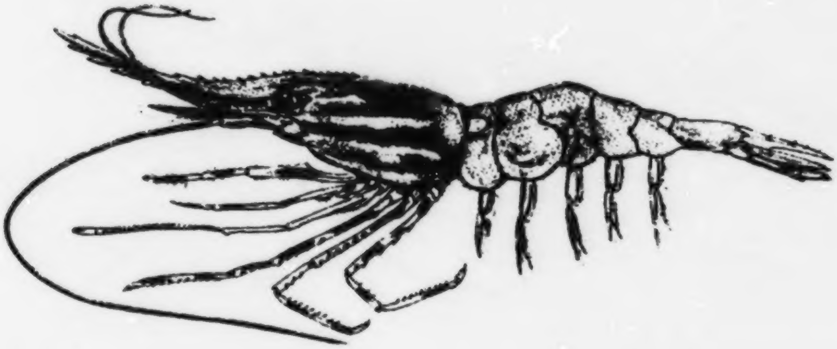
length to 150 mm; fine red dots over entire animal, with translucent background; concentration of red dots on dorsal surface and along ventral margin of carapace; antennae; dorsal segment of abdomen especially third to sixth segments, and parts of tail fan; prominent dorsal spines along the posterior margin and the bend of the third abdominal segment; posterior spine on the fourth abdominal segment, dorsal spines on rostrum



Crustaceans

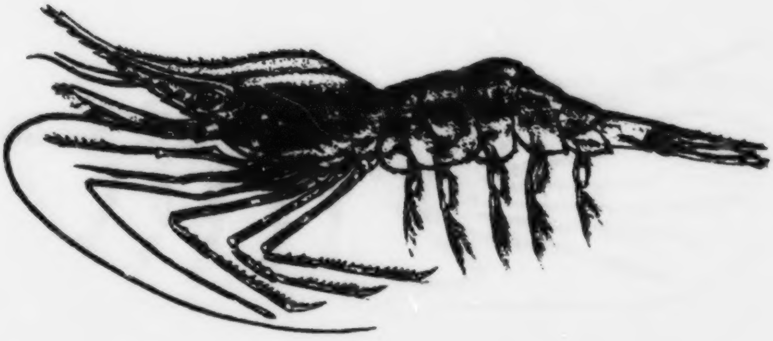
Prawn
Pandalus platyceros

length to 253 mm; adult colour somewhat "washed" out red to fawn or tan; 3 or 4 lateral white stripes prominent on carapace; round white spots in pairs on dorsallateral surface of first and fifth abdominal segments; alternating red and white bands on antennae; young animals darker on carapace normally with more white stripes and dots than adults, fine blue dots in pairs on anterior dorsal surfaces of first and third abdominal segments and on sides of carapace; stout body with carapace covered with fine hair-like projections; no dorsal spines on posterior half of carapace



Humpback Shrimp
Pandalus hypsinotus

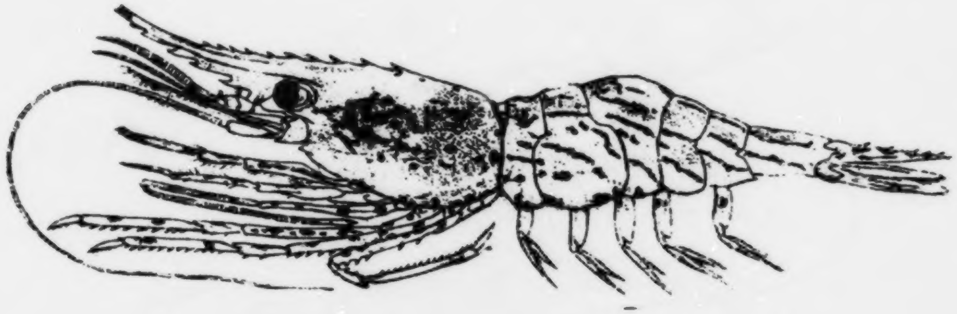
length to 192 mm; background colour light tan; carapace with pinkish area on midlateral surface overlaid with fine red dots; carapace sides to posterior dorsal spines chocolate brown to sooty black overlaid with mottling of red dots; other red dots along bases of dorsal spines and rostrum; sixth abdominal segment and tail fan partly chocolate brown; chocolate brown stripe on dorsal surfaces of fourth and fifth abdominal segment; brown to sooty black blotches on first to fifth abdominal segments; blotches of red spots on sides of first to fifth abdominal segments; stout body; smooth surface; strongly arched dorsal profile of carapace; sharply ascending rostrum; 17-22 dorsal spines on carapace



Crustaceans

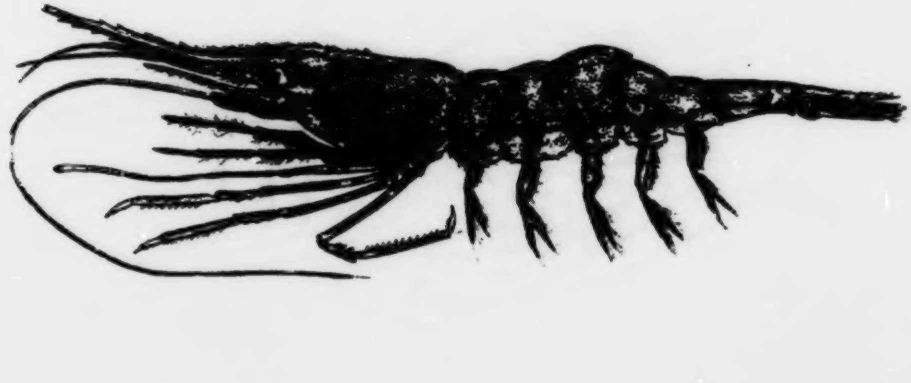
Coonstripe Shrimp *Pandalus danae*

length to 140 mm; milky translucent background, with irregular striping and spots of chocolate brown on lateral and dorsalateral surfaces of all abdominal segments and the telson of tail fan; lying between stripes are patches of fine brick-red dots; wide swath of brick red dots on sides of carapace posteriorly; eyestalk with outer red-brown patch; fine blue dots on mid-lateral carapace and dorsal surface of first to third abdominal segments; stout body with a short relatively ascending rostrum; rostrum normally three-pointed; no fine hair-like projections on carapace



Smooth Pink Shrimp *Pandalus jordani*

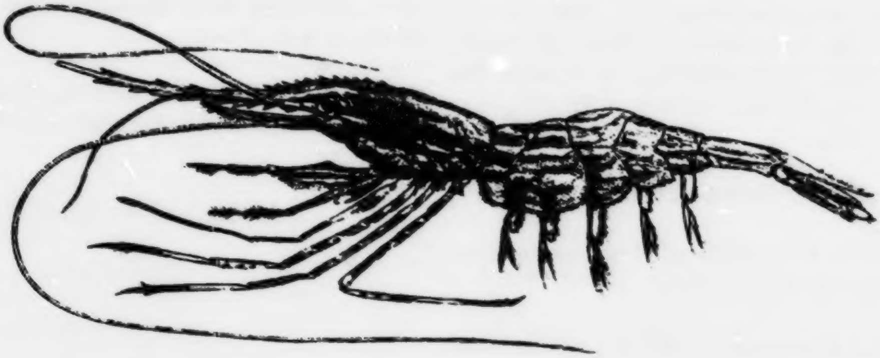
length to 175 mm; surface covered almost completely with fine red dots; dots distributed more densely on distal ventral margin of rostrum, telson of the tail fan, ventral side of sixth abdominal segment posteriorly and lower sides of carapace; similar in morphology to the pink shrimp except for the absence of a median dorsal spine on the posterior margin of the fourth abdominal segment



Crustaceans

Sidestripe Shrimp
Pandalopsis dispar

length to 208 mm; most of body and appendages reddish orange; rows of longitudinal white bars on dorsal and lateral surfaces of first to fifth abdominal segment; irregular white bars and patches on posterior half of carapace; first antennae more than twice as long as carapace; dorsal spines distributed along entire length of rostrum



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SALMONIDS

Salmonid descriptions and drawings closely follow:

Ellis, D.V. (ed.). 1977. Pacific Salmon - Management for People. Western Geographical Series, Volume 13, University of Victoria. 320p. In: D.B. Lister and Associates Ltd. and Kerr Wood Leidal Associates Ltd. 1980. Stream Enhancement Guide. Prepared for the Stream Enhancement Research Committee, Department of Fisheries and Oceans Canada and the B.C. Ministry of Environment, Vancouver, B.C. 82p.

Supplemental descriptions are taken from:

Hart, J.L. 1973. Pacific fishes of Canada. Fisheries Research Board of Canada Bulletin 180. 740p.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin 184. 966p.

NON-SALMONIDS

Descriptions of herring, lingcod, rockfish and surfperch are from:

Eschmeyer, W.N., E.S. Herald and H. Hammann. 1983. A Field Guide to Pacific Coast Fishes of North America, Houghton Mifflin Company, Boston, MA. 336p.

Hart, J.L. 1973. Pacific fishes of Canada. Fisheries Research Board of Canada Bulletin 180. 740p.

Drawings are from Hart (1973).

CRUSTACEANS

Description of Dungeness crab is from:

Gotshall, D.W. and L.L. Laurent. 1979. Pacific Coast Subtidal Marine Invertebrates. Sea Challengers, Los Osos, CA. 107p.

Descriptions and drawings of pandallid shrimp are from:

Butler, T.H. 1980. Shrimps of the Pacific coast of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences 202. 280p.

APPENDIX 5 *Fish Production Biostandards*

Abbreviations

CM - Chum
CN - Chinook
CO - Coho
PK - Pink
SK - Sockeye
ST - Steelhead

C - Coastal
I - Interior
K - Catchment
E - Escapement
F.R. - Fraser River

F - fry
S - smolts
A - adults

Tables

Table 5-1 Biostandards for Habitat Enhancement Projects

Project Type - Minimum Flow Control

Species	*Fry/Smolts*	*Reference*
CO	40 S/100sq.m	Marshall and Britton 1980
CN(C)	30 S/100sq.m	Slaney 1980
CN (I) (yearling)	45 S/100sq.m	Slaney 1980
ST(C)	2 S/100sq.m	Slaney 1980
ST(I)	10 S/100sq.m	Slaney 1980

Assumptions

CO	1) Enhancement increment is determined by difference in minimum wetted area of stream before and after flow control. 2) Overwintering capacity of stream or river system is adequate to accomodate increased fall standing crop of juveniles.
CN (C)	Same as 1) but flows are probably not a limiting factor on most coastal streams for juvenile production.
CN (I)	Same as 1) and 2)
ST (C)	Same as 1) and 2)
ST (I)	Same as 1) and 2)

Tables

Project Type - Production in Previous Non-salmonid Habitats: fishways; obstruction removal; colonization; gravel placements in non-gravel streams; CO, CN, and ST incubation boxes

Species	***Fry/Smolts***	***Reference***
CO	1400 S/km 40 S/100sq.m	Marshall and Britton 1980.
CN (C)	5800 S/km 30 S/100sq.m	Slaney 1980
CN (I)	5000 S/km 45 S/100sq.m	Slaney 1980
ST (C)	125 S/km 2 S/100sq.m	Slaney 1980
ST (I)	625 S/km 10 S/100sq.m	Slaney 1980
PK (F.R.)	26000 F/100sq.m	DFO 1981
PK (C - odd)	18000 F/100sq.m	DFO. 1981
PK (C - even)	20000 F/100sq.m	DFO 1981
CM	17000 F/100sq.m	DFO 1981
SK (F.R.)	40000 F/100sq.m	DFO 1981
SK (C)	30000 F/100sq.m	DFO 1981

Assumptions

Co	3) Production is determined by additional length/area of stream at low flow periods accessible to fish.
CN (C)	Same as 3) but small streams and headwater streams should not be included in estimates of suitable rearing habitat.
CN (I)	Same as 3) but small streams and headwater streams should not be included in estimates of suitable rearing habitat.
ST (C)	Same as 3)
ST (I)	Same as 3)
PK (F.R.)	4) Production is determined by additional area of spawning gravel accessible to adults.

Tables

PK (C)	5) Production is derived by assuming at least 1 female/sq.m and back calculating from S.E.P. biostandards. Same as 4) and 5) but assuming spawning densities of at least 1 female/1.5 sq.m.
SK (F.R.)	Same as 4) and 5) but assuming spawning densities of at least 1 female/1.5 sq.m.
SK (C)	Same as 4) and 5) but assuming spawning densities of at least 1 female/1.5 sq.m.

Project Type - Off-Channel Development: side channels with river intakes and gravel placements.

Species	***Fry/Smolts***	***Reference***
CO	40 S/100sq.m	Marshall and Britton 1980
CN (C)	30 S/100sq.m	Slaney 1980
CN(I)	45 S/100sq.m	Slaney 1980
ST (C)	2 S/100sq.m	Slaney 1980
ST (I)	10 S/100sq.m	Slaney 1980
PK (F.R.)	63000 F/100sq.m	Cooper 1977
PK (C - odd)	63000 F/100sq.m	Cooper 1977
PK	63000 F/100sq.m	Cooper 1977
CM	45000 F/100sq.m	Lister et al. 1980
SK (F.R.)	75000 F/100sq.m	Ginetz 1977
SK (C)	75000 F/100sq.m	Ginetz 1977

Assumptions

CO	6) Production is similar to natural streams
CN (C)	Same as 6)
CN (I)	Same as 6)
ST (C)	Same as 6)
ST (I)	Same as 6)
PK (F.R.)	7) Fry production/100sq.m is similar to Upper Seton River spawning channel at high spawning densities (1963).

Tables

Pk (C)	Same as 7)
CM	8) Fry production/100sq.m is similar to groundwater-fed side channels with gravel placement
SK (F R.)	9) Fry production/100sq.m is similar to Fulton River spawning at high spawning densities.
SK (C)	Same as 9)

Project Type - Off-channel Development: side channels with river intake and native gravels

Species	***Fry/Smolts***	***Reference***
CO, CN, ST	Same production as side channels with river intakes and gravel placements	Marshall and Britton 1980 Slaney 1980
PK (F.R.)	34000 F/100sq.m	McNeil 1969
PK (C - odd)	34000 F/100sq.m	McNeil 1969
PK (C - even)	34000 F/100sq.m	McNeil 1969
CM	24000 F/100sq.m	Sandercock 1975 Minaker 1979
SK (F.R.)	67000 F/100sq.m	West 1978
SK (C)	67000 F/100sq.m	West 1978

Assumptions

CO, CT, ST	Same as 6)
PK (F.R.)	10) Fry production/100sq.m is similar to Sashin Cr., Alaska, at densities of at least 1 female/sq.m and above average survival rates (1940, 1958, 1960, 1962 brood years)
PK (C)	Same as 10)
CM	11) Fry production/100sq.m is similar to Big Qualicum mainstem after flow control.
SK (F.R.)	12) Fry production/100sq.m is similar to Fulton River mainstem after flow control.
SK (C)	Same as 12)

Tables

Project Type - Off-Channel Development: side channels with river intakes developed for coho rearing (pools and riffles)

Species	*Fry/Smolts*	*Reference*
CO(1)	3000 S/km	Marshall and Britton 1980
CO(2)	133 S/100sq.m	Mundie 1969
ST(1) (C)	382 S/km	Slaney 1980
ST(2) (C)	10 S/100sq.m	Slaney 1980

Assumptions

CO(1)	13) Smolt production/km is similar to Big Qualicum mainstem after flow control.
CO(2)	14) Smolt production/100sq.m is derived from 13) assuming an optimum channel width of 4m.
ST(1)	15) Smolt production/km is similar to Big Qualicum mainstem after flow control
ST(2)	16) Smolt production/100sq.m is derived from 15) assuming an optimum channel width of 4m.

Project Type - Off-Channel Development: Groundwater-fed side channels with gravel placements

Species	*Fry/Smolts*	*References*
CO	40 S/100sq.m	Marshall and Britton 1980
CM	45000 S/100sq.m	Lister et al. 1980

Assumptions

CO	17) Smolt production/100sq.m is similar to natural streams
CM	18) Fry production/100sq.m is similar to Worth and Railroad Creeks at spawing densities greater than 0.5 females/sq.m

Tables

Project Type - Off-Channel Development: Groundwater-fed side channels with native gravels

Species	***Fry/Smolts***	***References***
CO	40 S/100sq.m	Marshall and Britton 1980
CM	27000 F/100sq.m	Lister et al. 1980

Assumptions

CO	Same as 17)
CM	19) Fry production/100sq.m is similar to Lower Paradise Channel at spawning densities of at least 0.5 females/sq.m

Project Type - Coho Overwintering Ponds

Species	***Fry/Smolts***	***References***
CO	120 S/100sq.m	Marshall and Britton 1980

Assumptions

CO	20) Smolt production/100sq.m is similar to Rotary Park, Bible Camp and Cowichan Side Channels, Cowichan River

Project Type - Rearing Habitat Complexing

Species	***Fry/Smolts***	***References***
CO	2,800 S/km	Ward and Slaney 1980
ST (C)	250 S/km 7 S/100sq.m	Ward and Slaney 1980

Assumptions

CO	21) Keogh River studies indicate twofold increase over natural levels.
ST (C)	Same as 21)

Tables

Project Type - Instream Supplementary Feeding

Species	*Fry/Smolt*	*Reference*
CO	8400 S/km 240 S/100sq.m	Mason 1974

Assumptions

CO

22) Studies by Mason (1974) indicate a sixfold increase in natural levels.

23) Overwintering capacity of stream or river system is adequate to accomodate increased Fall standing crop of juveniles.

Table 5-2 Mean Coho Smolt Production Densities and Mean Channel Gradients of Ten Puget Sound (Washington State) Streams (from Baranski 1989)

Stream	*Mean Gradient*	*Mean Smolts/m*	*Mean Smolts/sq.m*
Courteney Cr.	2.6%	0.35	0.12
Bear Cr.	3.4%	0.26	0.11
Mill Cr.	0.5%	0.88	0.12
Little Pilchuk Cr.	0.7%	1.54	0.08
Big Beef Cr.	1.0%	1.69	0.26
Mission Cr.	1.0%	0.78	0.21
Little Tahuya Cr.	1.0%	2.24	0.19
Harris Cr.	1.2%	1.86	0.19
Wildcat Cr.	1.4%	0.81	0.25
Lost Cr.	1.7%	0.76	0.25

Tables

Table 5-3 Mean Coho Smolt Production/m Relative to Percent Length Impounded and Percent Pool of Free-Flowing Length of Ten Puget Sound (Washington State) Streams (from Baranski 1989).

Stream	*Mean Smolt/m*	*% Length Impounded*	*% Pool of Free-Flowing Length*
Bear Cr.	0.26	0	44.9
Lost Cr.	0.76	0	45.5
Mission Cr.	0.78	0	49.1
Courtney Cr.	0.35	0	54.8
Wildcat Cr.	0.81	0	62.2
Big Beef Cr.	1.69	18.0	64.5
Mill Cr.	0.88	8.3	66.6
Harris Cr.	1.86	16.9	74.3
Little Tahuya Cr.	2.24	36.6	81.1
Little Pilchuk Cr.	1.54	44.4	92.0

Table 5-4. Estimates of Mean Annual Smolt Yields in Numbers and Biomass, and in Numbers and Biomass per Area and Length of Stream (from Marshall and Britton 1980).

Stream Area (m^2)	*Smolt Yield*				*Stream Length (km)*	*Smolt Yield*			
	No.	*kg*	*No./ $100m^2$*	*kg/ $100m^2$*		*No.*	*kg*	*No./ km*	*Kg/ km*
1,000	726	4.6	73	0.46	0.5	511	3.2	1,022	6.4
2,000	1,256	8.9	63	0.44	1.0	1,134	8.0	1,134	8.0
5,000	2,589	21.2	52	0.42	2.0	2,518	20.4	1,259	10.2
10,000	4,477	41.1	45	0.41	3.0	4,016	35.2	1,339	11.7
15,000	6,167	60.3	41	0.40	4.0	5,591	51.8	1,398	113.0
25,000	9,232	97.9	37	0.39	5.0	7,228	70.0	1,446	114.0
50,000	15,962	189.0	32	0.38	10.0	16,048	177.8	1,605	17.8
100,000	27,598	364.8	28	0.36	20.0	35,630	451.6	1,782	22.6
200,000	47,715	704.0	24	0.35	30.0	56,812	779.1	1,894	26.0

Tables

Mean variability: the mean production from a given stream of a given size plus or minus a certain percentage of the estimated smolt yield. Mean variability for the four combinations of smolt yield and rearing space variables are:

	Mean Variability (%)
numbers vs. area (m^2)	48
biomass (kg) vs. area (m^2)	38
numbers vs. length (km)	41
biomass (kg) vs. length (km)	43

Noteworthy trends in the above table are that large streams tend to be more productive per unit length than small streams but less productive per unit area, and that large streams tend to produce larger smolts than small streams.

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Glossary

accreted	net accumulation of sediments on a streambed
alevins	newly emerged, larval salmonid fry; juvenile salmonids with external yolk sac
anadromous	migrating from salt to fresh water to spawn
anaerobic	without oxygen
annual ring	one of the approximately circular bands observed when a branch or trunk of a shrub or tree is cut crosswise
apical	of or at the top; with reference to the apical bud of a stem which is the active (growth) bud on the end of stem
bathymetric	refers to the contours of an ocean bed or other large body of water
bloom	describing rapid production within a short period of time; rapid increase in density of an organism within a short period of time (e.g. algae bloom)
BOD	the amount of oxygen required to decompose organic matter in water
brackish water	a marsh of which ambient waters have a salinity range of approximately 0.5 to 17.0 parts per thousand
caliper	an instrument to measure the stem or trunk diameter of a shrub or tree, respectively; caliper size: the diameter of a stem or trunk at its widest point
compression	the process by which soil becomes firm or compact through the downward forces of overlying material; with reference to recently placed dredge spoil
datum	a reference point from which heights and depths are measured (e.g. tide elevations)
decomposer	an organism that obtains energy through the breakdown of dead organic matter into simpler substances; the term decomposer is usually applied to bacteria and fungi
demersal	found in deep water or on the ocean bottom
desiccation	the act of drying up
detrital	having the property of detritus: fresh to partly decomposed plant and animal matter that often includes bacteria and fungi
detritus	particulate organic material together with primary decomposer organisms such as fungi and bacteria
detrivore	an animal that feeds on detritus
diatom	one of a group of microscopic unicellular algae with shells that consist of two halves that fit like a box

diffusion	the transfer of oxygen molecules from air to water
drift	invertebrates, composed predominantly of insects, suspended within the water column, moving downstream
ecosystem	a unit consisting of a community of organisms and their physical environment (see Chapter 1)
effluent	the liquid waste of sewage and industrial processing
escapement	the number of adult fish that "escape" fishing gear to migrate upstream to spawning grounds
establishment	initial growth of plants under a given set of physical conditions; with regard to marsh transplants, where plants may grow in the first or second season, but not necessarily in subsequent seasons (see persistence)
eutrophic	over-rich in nutrients, either naturally or artificially as a result of pollutants
exoskeleton	the outer hard parts of an organism (e.g. "shell" of a crab)
fauna	an assemblage of animals
fecundity	potential of an organism to produce eggs or young
fetch	wind generated waves
fluvial	of or belonging to rivers
food chain	a series of steps through which energy is passed from one group of organisms to another, series commencing with producers (plants) and terminating with consumers (herbivores and carnivores)
food web	a series of interconnecting food chains
fresh marsh	a marsh of which ambient waters have a salinity less than approximately 0.50 parts per thousand
green eggs	unfertilized eggs
greenwood	the soft tip of the stem after the spring flush of growth
groin	a barrier built, usually of large boulders, out from the shore to protect against erosion and sand movement
hardwood	the fully mature stem of a deciduous tree or shrub
heel cutting	a young side shoot that is stripped away from the main stem so that thin sliver of bark and wood (heel) from the main stem accompanies the side shoot
herbaceous	refers to a plant with no woody parts above the ground

hypersaline	with reference to intertidal soils, possessing salinities greater than 40 parts per thousand
interstitial	the spaces between objects (e.g. streambed gravels)
innundation regime	flooding environment referring to the period of submergence and emergence
invertebrate	an animal lacking a backbone
jetty	see groin
light extinction coefficient	a value for a given set of physical and biological parameters of water, indicating the level of alteration in both quantity and quality of solar energy due to absorp tion and scattering of light rays
litter corridor	the area within a marsh where organic litter accumulates
mallet cutting	similar to heel a cutting, with a second horizontal cut so that the side-shoot is isolated with a small "mallet" of main stem
maximum surface incident light	maximum light striking the waters surface
megalops	the final developmental stage of a crab or shrimp
monotypic	of one species; refers to a marsh community consisting of only one species
moulting	with reference to invertebrates, the process of shedding an exoskeleton during growth (e.g. crab)
motile	being capable of spontaneous movement
natal stream	the stream in which a fish was spawned
oxygen saturation	the maximum concentration of oxygen in water; the saturation concentration decreases as water temperature increases
pelagic	living or growing near the surface of the ocean
persistence	where a plant maintains itself indefinitely subsequent to establishment
physiological shock	a disruption of the normal organic functions of an organism, with reference to the metobolic stress induces on a plant during transplant
piling	a cylindrical or flat member of wood, steel, or concrete hammered into the ground to form a tie support for log storage or a sheer boom, or compose a foundation or retention wall
productive capacity	the maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms upon which fish feed

primary production	production by green plants
propagule	a propagative part, such as a seed or cutting
ppm	parts per million
redd	the spawning area or nest of trout and salmon
riparian zone	the area immediately adjacent to a stream or river
rough bottom	with reference to those fisheries that catch fish, such as **fisheries** rockfish and lingcod, that inhabit reefs and rocky bottoms
salmonid	a fish belonging to the family Salmonidae, including salmon, trout, char and allied freshwater and anadromous fishes
salt marsh	a marsh of which ambient waters have a salinity greater than approximately 17.0 parts per thousand
secchi disk	an opaque white disk with black markings used to measure the transparency or clarity of water
secchi disk depth	the greatest depth at which a Secchi disk can be visually detected
semi-ripe cutting	cutting taken from the most immature part of the stem at the end of the growing season
settlement	the process by which soil becomes firm or compact through the settling of smaller particles amongst larger particles
softwood cutting	cutting taken from the most immature part of the stem during the spring
smolt	a seaward migrating juvenile salmonid, silvery in colour, that has become thinner in body from and is physiologically prepared for the transition form fresh to saltwater
soil creep	the slow, steady downhill movement of soil and loose rock on a slope
terminal bud	that bud that develops at the apex of a stem or branch
terminal bud scar	the scar demarking the present seasons's growth of a branch from the previous season's
thalweg	the path of maximum depth along a stream or river
tillage	loosened surface substrates to facilitate successful seed germination and seedling growth
topographic	refers to physical relief features or surface configuration of land
trophic level	feeding levels within a food web composed of many distinct groups of organisms

vegetative	those parts of a plant that serve a nutritive or growth function, as opposed to sexual structures that produce pollen and ovules
wakes	boat generated waves
water harden	with reference to a fertilized fish egg, when water is drawn into the egg until it becomes turgid or hard
wetland edge	the interface between wetland vegetation and open water
zoeamegalops	the final larval stage of crabs and shrimp; the larval stage of crabs and most shrimp at which settlement to the ocean bottom occurs
zoea	a shrimp-like larval crab